NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

THE LATERAL RESPONSE
OF AN AIRSHIP TO TURBULENCE

by

John J. Wrobleski, Jr.

December 1981

Thesis Advisor: Donald M. Layton

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
The Lateral Response of an Airship to Turbulence

5. TYPE OF REPORT & PERIOD COVERED
Master's Thesis;
December 1981

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
John J. Wrobleski, Jr.

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Naval Postgraduate School
Monterey, California 93940

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Naval Postgraduate School
Monterey, California 93940

12. REPORT DATE
December 1981

13. NUMBER OF PAGES
150

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Airships
Lateral Response
Turbulence

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
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and loading occur when the encountered spectral component has a wavelength equal to the airship length, and that simple feedback of heading angle does not significantly decrease this peak.

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The Lateral Response of an Airship to Turbulence

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Submitted in partial fulfillment of the
requirements for the degrees of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

and

AERONAUTICAL ENGINEER

from the

NAVAL POSTGRADUATE SCHOOL
December 1981

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NOMENCLATURE

A	hull cross-sectional area
B	total buoyancy force of the airship, $\rho \cdot g \cdot$volume
BM	hull bending moment about the vertical axis distributed along the hull longitudinal axis
$\bar{c}$	longitudinal characteristic length of the airship
$\bar{c}_s$	mean chord of fin
$\tilde{C}$, $\tilde{D}$	matrix of coefficients from equation 51
C_y	nondimensional aerodynamic force in the y-direction, $C_y = 2Y/\rho U_o{}^2 S$
$C_{l,n}$	nondimensional aerodynamic rolling and yawing moments respectively, $(C_l, C_n) = 2(L,N)/\rho U_o{}^2 S\bar{c}$
C_L	nondimensional aerodynamic lift
$(C_L{}^*)_s$	C_L for the fins alone, no hull interference
C_s	nondimensional shear force $C_s = 2S(l)/\rho U_o{}^2 S$
C_{BM}, C_{TM}	nondimensional bending and twisting moment respectively, $(C_{BM}, C_{TM}) = 2(BM,TM)/\rho U_o{}^2 S\bar{c}$
$D(\ )$	nondimensional time derivative, $(c/2U_o)d(\ )/dt$
g	gravitational acceleration
G_{Y_γ}, G_{l_γ}, G_{n_γ}	turbulence forcing functions (equation 59)
h	body-fixed coordinate measured normal to the hull centerline (positive up)

h_{cm}	h location of the vehicle's mass center
$(h_{cm})_s$	h location of the empennage-assembly's mass center
$H(k)$	Sears' function corrected for finite aspect ratios by Filotas [Ref. 16]
I_{xx}, I_{zz}	moments of inertia about the x- and z-axes
I_{xz}	product of inertia w.r.t. x- and z-axes
i_{xx}, i_{zz}, i_{xz}	nondimensional moments and product of inertia $i_{xx} = 8I_{xx}/\rho S\bar{c}^3$
i	imaginary operator, $i = \sqrt{-1}$
K	hull potential cross-flow factor from Jones and DeLaurier [Ref. 6]
k_1, k_2	axial and traverse apparent-mass coefficients
k_c	control gain of fin normal force to vehicle azimuth angle
l	axially-aligned body-fixed coordinate originating at the nose
l_b	axial location of the buoyancy center
l_h	axial location of the hull-fin intersection point
l_s	axial location of the fin's aerodynamic center
l_{cm}	axial mass-center location of the entire vehicle
$\tilde{L}$	turbulent scale length
L	rolling moment
m	mass of the entire vehicle, including internal air and gas
m_s	mass of the empennage assembly
N	yawing moment

p	vehicle angular velocity about the x-axis
$\hat{p}$	nondimensional value of p, $\hat{p} = (\bar{c}/2U_o)p$
$\hat{P}$	nondimensional maximum value of $\hat{p}$
r	vehicle angular velocity about the z-axis
$\hat{r}$	nondimensional value of r, $\hat{r} = (\bar{c}/2U_o)r$
$\hat{R}$	nondimensional maximum value of $\hat{r}$
$R(\tau)$	auto-correlation function
S	reference area of airship, $(\text{volume})^{2/3}$
$S(l)$	hull shear force, normal to the centerline
S_s	stabilizer reference area (planform area)
t	time
TM	twisting moment, about the hull axis
U_o	reference flight speed
v	perturbation velocity of the vehicle's mass center in the y-direction
$\hat{v}$	nondimensional value of v, $\hat{v} = v/U_o$
$\hat{V}$	nondimensional maximum magnitude of $\hat{v}$
v_g	horizontal velocity of the atmospheric turbulence
x, y, z	body-fixed wind-aligned stability axes (x positive forward, y positive right, z positive down)
x', y', z'	axes fixed in inertial space
Y	force in the y-direction

GREEK SYMBOLS

α_o	reference aerodynamic relative angle of attack
β	aerodynamic sideslip angle

γ	horizontal nondimensional velocity of the spectral component
Γ	maximum value of γ
η_s	stabilizer efficiency factor, from Jones and DeLaurier [Ref. 6]
μ	nondimensional mass, $\mu = 2m/\rho S\bar{c}$
ξ	axial coordinate, measured from the nose
ρ	atmospheric density
σ	turbulence intensity
$\hat{\sigma}$	nondimensional stability root
ϕ	roll angle
Φ	maximum value of ϕ
$\Phi_{jj}(\Omega)$	power-spectral function for turbulence component v_g
ψ	azimuth angle
Ψ	maximum value of ψ
ω	spectral component frequency
Ω	wave number

SUBSCRIPTS

$(\ )_{aero}$	aerodynamic force or moment terms
$(\ )_B$	buoyancy terms
$(\ )_c$	control terms
$(\ )_{cm}$	mass center terms
$(\ )_{emp}$	term for entire empennage assembly
$(\ )_g$	atmospheric-turbulence term

$(\ )_h$	hull term
$(\ )_m$	inertial term
$(\ )_o$	reference equilibrium value
$(\ )_p$	derivative w.r.t. $\hat{p}$
$(\ )_{\dot{p}}$	derivative w.r.t. $D\hat{p}$
$(\ )_r$	derivative w.r.t. $\hat{r}$
$(\ )_{\dot{r}}$	derivative w.r.t. $D\hat{r}$
$(\ )_s$	fin term
$(\ )_T$	thruster-rotor term
$(\ )_v$	derivative w.r.t. $\hat{v}$
$(\ )_{\dot{v}}$	derivative w.r.t. $D\hat{v}$
$(\ )_\beta$	derivative w.r.t. β
$(\ )_{\dot{\beta}}$	derivative w.r.t. $D\beta$

SUPERSCRIPTS

$(\hat{\ })$	nondimensional term
$(\dot{\ })$	derivative w.r.t. time

ACKNOWLEDGMENT

This thesis was supported with funds from the United States Coast Guard Airship Office.

Tha author would like to thank Mr. Peter Talbot of NASA for his help in obtaining references and information on the current state-of-the art in the airship field and Dr. James DeLaurier of the University of Toronto for his help in finding sources and suggesting methods of analysis. His review of the equations in Chapter III did much to ensure the accuracy of that derivation. Finally, the author is greatly indebted to his advisor, Professor Donald M. Layton, for his guidance and support. His time spent as a pilot in the Navy's airship community, together with his historical insight, were invaluable in ensuring the work undertaken was meaningful and in accordance with experience.

I. INTRODUCTION

When a close look is taken of the history of airship flight, it becomes evident that turbulence is a prime cause for concern in the design of lighter-than-air (LTA) craft. The spectacular crashes of the airships Shennandoah, Akron, and Macon are perhaps the most obvious reminders of the powerful effect the wind can have on these fragile vehicles. It is imperative that proper consideration be given to the gust response of an airship, both dynamically and structurally.

At the time the great rigids were built, designers had only a cursory knowledge of turbulence and how to deal with it. Burgess [Ref. 1], for example, dedicates only one page to the subject, and that is mainly a warning that gusts encountered in flight can place larger loads on an airship than any maneuver of which it is capable. He suggests using the standard gust analysis technique of the day--a "fixed-in-space" flight through a ramp shaped gust. This was the method used to evaluate all aircraft at the time, and provided some measure of confidence that the structure would withstand the stresses of flight. Its principal weakness was that it took into account only the direct gust loads.

Since that time, the methods used to analyze response to turbulence have been greatly improved. Over time, the ramp shaped gust gave way to other gust shapes, finally settling

on the (1-cosine) gust as standard [Ref. 2]. By the mid-fifties enough data had been gathered on the nature of the turbulent wind to derive some basic statistical relations. This, in turn, allowed the development of the power spectral method for aircraft load analysis (see, for example, Press and Meadows [Ref. 3]). The spectral method has been applied to many types of aircraft over the last twenty years. At present, both methods are used in analysis of flight structures, the one giving the more conservative structure determining the final design.

While the development of turbulence modeling techniques progressed, applications to airship technology were slower in coming. Because the success of heavier-than-air (HTA) craft made the slower airship economically less attractive, LTA research lagged. In the period between World War II and the Arab Oil Embargo of 1973, the only significant contribution to the study of airships in turbulence was by Calligeros and McDavitt [Ref. 4]. This paper presented a method of analysis that allowed a stable airship to respond dynamically to both sinusoidal and (1-cosine) gusts. Thus, the inertial and aerodynamic reaction forces of gust encounter could be included in the model. Further, by using the sinusoidal representation for gust shape, it was possible to apply spectral methods to the analysis.

The recent interest in LTA brought about by rising fuel costs has increased the research in all aspects of airship

flight. The spectre of the great rigids disintegrating in turbulence makes it imperative that the designer have adequate means to predict an airship's response to gust penetration. Current research is aimed at supplying that means. DeLaurier and Hui [Ref. 5] refined the technique of Calligeros and McDavitt [Ref. 4], by introducing refinements to the aerodynamic cross-flow model [Ref. 6] and allowing for stability augmentation through pilot control input. The model allows statistical prediction of an airship's dynamic response and operational lifetime for various combinations of speed, altitude and control gain.

DeLaurier and Hui's work (as well as most others dealing with this subject) concentrated only on the longitudinal aerodynamic case. This thesis proposes to apply their model to the lateral case, enabling the response to side-force to be calculated. Bending and shear in the horizontal plane, as well as twisting moment, can then be taken into account when predicting airship life expectancies.

II. THE TURBULENT WIND

The motion of the atmosphere is very complex. Shearing stress between layers of different speeds and at the ground, thermals caused by solar heating, weather fronts, vortex shedding behind obstructions and aircraft, plus many other phenomena, all contribute to a velocity field that is most difficult to describe. Of the methods available, that chosen will depend on the purpose for which it is used. A goal in the design of any flight vehicle is safety, with performance adequate for the mission. This dictates using models giving reasonable estimates for the design parameters, and it may or may not be necessary to closely match the physical reality to do this. In any case, the designer must be familiar with the advantages and limitations of methods available in order to choose wisely. What follows is a brief review of some of the turbulence models currently in use and how they apply to airship analysis.

A. THE DISCRETE GUST

As mentioned in the introduction, the discrete gust model has been used to analyze aircraft for many years. It is especially good when response to the passage through a steady velocity gradient, such as a thermal, mountain updraft, or jet stream, is desired. The method has been improved

steadily until, as Etkin [Ref. 7] points out, it has attained a high degree of sophistication.

Figure 1 shows the shape for a (1-cosine) gust, where W_m and d_m are maximum gust velocity and distance along the flight path of this maximum. By varying these parameters, the gust severity can be controlled. The value for d_m is prescribed by the Federal Aviation Administration (FAA) as

$$2d_m = 25\bar{c}$$

The size of W_m is dependent on airspeed and altitude, and is shown in figure 2 for three values of equivalent airspeed. The $25\bar{c}$ wavelength was chosen because it historically couples with the short period pitch mode of a rigid aircraft to produce the largest load factors. Calligeros and McDavitt [Ref. 4] showed that, for airships, the maximum loads occur when the wavelength is equal to the airship length.

The British dictate (ARB CAR CH D3-3) that the gust parameters be chosen to produce the peak response with aircraft flexibility taken into account. In this way, the model is "tuned" to the aircraft, thus assuring a conservative design.

B. RANDOM TURBULENCE

Extensive measurements of the atmospheric velocity field have been made, and the techniques involved are well established and reliable [Ref. 2]. They show that the velocity vector is best characterized by a random function of space

and time that is, in general, non-homogeneous, non-stationary, and anisotropic. The exact function has not been developed due to its tremendous complexity. Until enough data is collected (if ever) to allow the precise formulation, certain simplifying assumptions must be made to enable flight vehicle analysis.

One assumption that applies everywhere except in the planetary boundary layer (below about 1000 ft), is that the turbulence is 'homogeneous', that is, the statistics of the field do not vary through space. In the boundary layer, scale length and intensity are homogeneous in the horizontal plane, but not vertically. Another assumption made is that the turbulence is 'stationary', or statistically time constant. Over the time periods of interest to flight this approximation is quite adequate. Also, the turbulence is assumed to be isotropic (again, except in the boundary layer), making the statistics invariant with orientation.

One last simplification used to model atmospheric turbulence is the 'frozen field' or Taylor's hypothesis [Ref. 8]. The change in the velocity field perceived by an aircraft as it passes with speed U_o through the air is given by the substantial derivative

$$\frac{D(\ )}{Dt} = \frac{\partial(\ )}{\partial t} + U_o \frac{\partial(\ )}{\partial x}$$

Taylor's hypothesis states that for all but the smallest values of U_o, the second term dominates and the first may be ignored. The result is that the correlations and spectra reduce to three-dimensional functions of space only. Physically, this means the velocity field is 'frozen' in time, and the changes are due only to displacement.

In an effort to specify an acceptable lower limit on U_o, for which the frozen field applies, Dobrolenskiy [Ref. 9] cites studies comparing records of turbulence spectra gathered by captive balloon and an aircraft flying nearby at the same time. Within the margin of error, the two are statistically quite similar, and he concludes the lower limit on U_o is comparable to the convection velocity (for all practical purposes, the mean wind speed). Etkin [Ref. 7] points out that the vehicle speed can be as low as one-third the wind speed for good results. Note that the only vehicles capable of less than this velocity are LTA and VTOL craft, and then only when they are convected downwind with the airmass. In hover, or upwind flight, the hypothesis holds. For that small portion of the flight envelope in which it does not, the forces generated on an airship's structure are small and, therefore, do not present a problem.

The techniques for dealing with isotropic, frozen turbulence are well known [Ref. 8]. For those not familiar with the mathematical background necessary to deal with the

subject in depth, Chapters 2, 3, and 13 of Etkin [Ref. 10] will provide a good primer.

1. Turbulence Organization

Anyone who has seen leaves swirl on an autumn day, or watched someone blow smoke rings, has an intuitive understanding that the motion of the atmosphere is not completely arbitrary. What happens at one location effects conditions at another. Fuidynamicists characterize this interdependence by using expressions relating the stress and strain in the fluid. The technique has been applied to turbulence [Ref. 11] with some success in predicting the actual velocity field of a boundary layer type flow.

For flight vehicle analysis, a more convenient method of specifying the velocity field is the spectral decomposition of the three-dimensional homogeneous vector field [Ref. 12]. Figure 3 shows an aircraft flying through a (two-dimensional) sinusoidal wave of shearing motion. The velocity change from the mean is given (for the lateral gust component) by

$$dv_g(x',y') = e^{i(\Omega_1 x' + \Omega_2 y')} \, dc_2 \qquad (1)$$

where Ω_1 and Ω_2 are the wave number components in the x' and y' directions respectively, and c_2 is the complex amplitude of the lateral component. If the vehicle penetrates the

field with velocity U_o, the coordinates become $x' = x + U_o t$, and $y' = y$ in the body fixed system. Equation (1) then becomes

$$dv_g(x,y) = e^{i\Omega_1 U_o t} e^{i(\Omega_1 x + \Omega_2 y)} dc_2 \tag{2}$$

The air velocity over the vehicle is then periodic with wavelengths $(2\pi/\Omega_{1,2})$ and frequencies $(\Omega_{1,2} U_o/2)$. The total field is made up of the superposition of these spectral components, much as a Fourier series represents a random scalar.

2. Probability Distribution and Spectra

With the expression for a single spectral component available, the next difficulty is determining the probability distribution of the individual frequencies. The power spectral density of a time varying function, $X(t)$, is defined (in terms of wave number) as

$$\Phi(\Omega) = \lim_{\substack{\Delta\Omega \to 0 \\ T \to \infty}} \frac{1}{T\Delta\Omega} \int_0^T X(t,\Omega,\Delta\Omega)\,dt \tag{3}$$

where $\Phi(\Omega)$ is expressed in $(\text{ft/sec})^2/(\text{radians/ft})$, and T is the duration over which $X(t)$ is measured. The value is usually computed by taking the autocorrelation function $R(\tau)$ [Ref. 10: Chapter 2], and performing a Fourier transformation, thus

$$\Phi(\Omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} R(\tau)e^{i\Omega\tau}d\tau \qquad (4)$$

Figure 4 [Ref. 2] shows the spectra of three different meteorological conditions. While varying in detail, they all exhibit the same decreasing trend at higher frequency. The vertical dimension is a measure of the intensity of the turbulence at that particular frequency, and the square root of the area under the curve a measure of the overall rms gust velocity [Ref. 13]. As a point of practicality, only the area under the actual measured curve is included, because values of the spectrum at higher frequencies contribute little to the response of an aircraft.

From analyzing large numbers of samples, it is apparent the probability distribution is non-Gaussian [Ref. 14], with very high and very low values of intensity occurring more frequently than predicted by a normal distribution. However, the vast majority of values do fall on a Gaussian curve, so it is reasonable to use this assumption for most applications. This is very beneficial because, whereas Gaussian input to a linear system results in Gaussian output, response to non-Gaussian input is, in general, unknown. In the analysis of flight vehicles, linear system models are used extensively, making the assumption of normal distribution most desirable. In order to account for the large gusts omitted by this type model, the (1-cosine) method can

be employed. This is the practice recommended by many certifying agencies.

Two Gaussian models in current use are the Dryden spectrum

$$\Phi_{33}(\Omega) = \frac{\sigma^2\tilde{L}}{\pi} \frac{1 + 3\tilde{L}^2\Omega^2}{(1 + \tilde{L}^2\Omega^2)^2} \tag{5}$$

and the von Kàrmàn spectrum

$$\Phi_{33}(\Omega) = \frac{\sigma^2\tilde{L}}{\pi} \frac{1 + \frac{8}{3}(1.339\tilde{L}\Omega)^2}{[1 + (1.339\tilde{L}\Omega)^2]^{11/10}} \tag{6}$$

The first was developed to define turbulence spectra in wind tunnels. It is the simpler of the two, but not as accurate as the second. For that reason it is not used as much today as in the past, but is mentioned here due to its historical significance and the large number of references to it in the literature.

Today, the von Kàrmàn spectrum is used almost universally. In equation (6), σ is the rms turbulence intensity, and $\tilde{L}$ is the "scale length"--a measure of the average eddy size encountered. Testing has shown that the model is a reasonable fit to all levels of turbulence. Figure 5 is a plot of one set of experimental data along with the predicted turbulence spectra for severe storm conditions using various values for $\tilde{L}$. As can be seen, the agreement is quite good.

The values for σ and $\tilde{L}$ are variable and appear to be functions of altitude. In addition, two standard categories of intensity are defined--"storm" and "non-storm". Table I [Ref. 15] lists values for non-storm (b_1) and storm (b_2) intensities, as well as scale length, currently used by NASA for horizontal atmospheric flight. In this table, the values p_1 and p_2 are the probabilities of encountering non-storm and storm turbulence, respectively, at the altitude specified. Note that the values of $\tilde{L}$ given for flight below 1000 ft are representative values that are probably low, giving conservative (high) numbers of load exceedances per unit length of flight. These values are usable for structural analysis, but inappropriate for control system studies of flight simulation where the vertical inhomogeneity must be taken into account.

Equation (6) is the expression for the transverse spectrum needed to analyze the longitudinal response to vertical gusts. When dealing with lateral aerodynamics, such as the analysis done in Chapter III, it is necessary to use the longitudinal spectrum

$$\Phi_{11}(\Omega) = \frac{\sigma^2\tilde{L}}{\pi} \frac{2}{[1 + (1.339\tilde{L}\Omega)^2]^{5/6}} \tag{7}$$

where σ and $\tilde{L}$ are the same as in the transverse case. The term "longitudinal" refers to the variation in gust velocity parallel to the direction of the mean wind, whereas

"transverse" refers to the perpendicular direction (both vertically and horizontally), thus

$$\Phi_{22} = \Phi_{33}$$

It should be obvious from this discussion that flight direction relative to the mean wind becomes important when dealing with lateral aerodynamics.

III. METHOD OF ANALYSIS

A. THE MODEL

The aerodynamic model used in this analysis is the same as used by DeLaurier and Hui [Ref. 5], except that it is applied for the lateral case. The assumptions are as follows:

i) the vehicle is perfectly rigid, flying at a reference velocity U_o through a constant density ρ

ii) the motions are described by the lateral case only

iii) the control provided by rudder deflection is linearly proportional to the yaw angle (ψ), that is, $\Delta C_{Y_c} = k_c\psi$

This last assumption is the case for a helmsman using greater control the farther off heading he is perturbed, an assumption in keeping with operational practice.

The turbulence model used is the von Kàrmàn spectra described in Chapter II. It is assumed that the turbulence is composed of horizontal gusts only--either u_g or v_g depending on airship heading relative to the mean wind direction. (v_g is shown in the analysis.)

1. Forces from Turbulence Components

From Jones and DeLaurier [Ref. 6], the normal force on a hull segment of length $d\xi$ is (see figure 6)

$$F_h = \frac{1}{2}\rho U_o^{\,2}[K \sin(2\theta) \cos\left(\frac{\theta}{2}\right) \frac{dA}{d\xi}\, d\xi + (C_{d_c})_h \sin\theta \sin|\theta|\ 2r d\xi] \tag{8}$$

where: K is the hull potential cross-flow factor [Ref. 6]

θ is the angle between the hull centerline and U_o

r is the radius of the hull segment.

Differentiating with respect to θ to obtain a perturbation equation gives

$$dF_h = \frac{1}{2}\rho U_o^2\left[\left(-\frac{K}{2}\sin(2\theta)\sin\left(\frac{\theta}{2}\right) + 2\,K\cos(2\theta)\cos\left(\frac{\theta}{2}\right)\right)d\theta\frac{dA}{d\xi}d\xi + (C_{d_c})_h(\cos\theta\sin|\theta| + \sin\theta\cos|\theta|)d\theta\,2r\,d\xi\right]$$

By limiting the analysis to the lateral aerodynamic case only, (θ) becomes (β), the sideslip angle, and F_h becomes Y_h, the hull sideforce. Further, if (β_o), the undisturbed value of sideslip, is assumed to be zero--the usual case--the above expression becomes

$$(dY_g)_h = \frac{1}{2}\rho U_o^2 K\frac{dA}{d\xi}\left[2\cos(2\beta_o)\cos\left(\frac{\beta_o}{2}\right)\right]d\beta_o\,d\,\xi$$

$$= \rho U_o^2 K\,\frac{dA}{d\xi}\,d\xi\,d\beta$$

Finally, for small values of v_g,

$$d\beta = \frac{v_g}{U_o}$$

and

$$(dY_g)_h = \rho U_o^2\,K\frac{dA}{d\xi}d\xi\,\frac{v_g}{U_o} \qquad (9)$$

The stabilizer forces are given by

$$(Y_g)_s = \rho \frac{U_o^2}{2} S_s (C_{L_\alpha}^*)_s H(k_s) \eta_s \frac{(v_g)_s}{U_o} \tag{10}$$

where: $H(k_s)$ is the generalized Sears function as given by Filotas [Ref. 16]

$k_s = \frac{\omega \bar{c}_s}{2U_o}$, the "reduced frequency" of the fin

$(v_g)_s$ is the gust velocity at the fin mid-chord

The propellers used to drive the airship produce a side force when acted by the turbulence [Ref. 17]. Each thruster contribution adds to the total force and moment produced, and can be described, for the jth thruster-rotor combination by the following:

$$(Y_g)_{T_j} = -\rho \frac{U_o^2}{2} S_{T_j} (C_{Y_\beta})_{T_j} \frac{(v_{g_T})_j}{U_o} \tag{11}$$

$$(L_g)_{T_j} = (Y_g)_{T_j} (h_{cm} - h_{T_j}) \tag{12}$$

$$(N_g)_{T_j} = (Y_g)_{T_j} (l_{cm} - l_{T_j}) \tag{13}$$

Equations (12) and (13) assume that the rotors are arranged symmetrically about the x-z plane, so that moments due to rotor offset in the y-direction cancel out.

2. Aerodynamic Forces and Moments Due to Airship Motion

$$(dY_w)_h = \rho U_o^2 K \frac{dA}{d\xi} d\xi \frac{v(\xi)}{U_o} + \rho A\left[k_2 \frac{\partial v(\xi)}{\partial t} + U_o r k_1\right] d\xi \qquad (14)$$

where k_2, k_1 are the horizontal and longitudinal apparent mass coefficients respectively and

$$v(\xi) = v - r[(l_{cm} - \xi)]$$

For the fins we have

$$(Y_w)_s = -\rho \frac{U_o^2}{2} S_s \left[\left(C_{Y\beta}\right)_s \frac{v_s}{U_o} + \left(C_{Yr}\right)_s^{ac} \frac{\bar{c}r}{2U_o} + \left(C_{Y\dot{\beta}}\right)_s \frac{\bar{c}\dot{v}_s}{2U_o^2}\right] \qquad (15)$$

where $v_s = v - r(l_{cm} - l_s)$

$$\dot{v}_s = \dot{v} - \dot{r}(l_{cm} - l_s)$$

$$(L_w)_s = (Y_w)_s (h_{cm})_s \qquad (16)$$

$$(N_w)_s = \frac{1}{2}\rho U_o^2 S_s \bar{c}_s \left(C_{n_r}\right)_s^{ac} \frac{\bar{c}r}{2U_o} \qquad (17)$$

The superscript ac indicates the quantity in parentheses is taken about the fin aerodynamic center.

Thruster forces and moments are given by:

$$(Y_w)_{T_j} = -\rho \frac{U_o^2}{2} S_{T_j} (C_{Y\beta})_{T_j} \frac{(v_T)_j}{U_o} \qquad (18)$$

$$(L_w)_{T_j} = (Y_w)_{T_j} (h_{cm} - h_{T_j}) \qquad (19)$$

$$(N_w)_{T_j} = (Y_w)_{T_j} (l_{cm} - l_{T_j}) \tag{20}$$

where

$$(v_T)_j = v - r(l_{cm} - l_{T_j}) - p(h_{cm} - h_{T_j})$$

3. <u>Inertial Reaction of Airship to Aerodynamic Forces and Moments</u>

The "forces" covered here are those arising as reactions to airship motion. They are, in general, the negative of the forces and moments that give rise to the indicated airship translational and angular velocities and accelerations so as to produce a state of dynamic equilibrium ($\bar{F} - m\bar{a} = 0$).

For the hull:

$$(dY_m)_h = -\ddot{y}'(\xi)(d_m)_h \tag{21}$$

where $\ddot{y}' = \dot{v} + \dot{r}(l_{cm} - \xi) + U_o r$

$$(dL_m)_h = -dI_{xx}\dot{p} + dI_{xz}\dot{r} \tag{22}$$

$$(dN_m)_h = -dI_{zz}\dot{r} + dI_{xz}\dot{p} \tag{23}$$

For the empennage:

$$(Y_m)_s = -\ddot{y}'_s \, m_s \tag{24}$$

$$(N_m)_s = -(I_{zz})_s\dot{r} + (I_{zx})_s\dot{p} \tag{25}$$

$$(L_m)_s = -(I_{xx})_s\dot{p} + (I_{zx})_s\dot{r} \tag{26}$$

where dI_{xx}, dI_{zz} and dI_{xz} are the moments and product of inertia respectively of the differential element under consideration, including all structure, air and gas contained in the airship.

4. Bouyancy and Control Terms

Referring to figure 7, the force due to bouyancy is given by:

$$(Y_b)_h = -(gdm - \rho gAd\xi) \sin\phi \cos\alpha_o$$

$$\phi = \text{roll angle}$$

$$\alpha_o = \text{steady state angle of attack}$$

Differentiating to obtain a perturbation equation gives

$$(dY_b)_h = (\rho gAd\xi - gdm) \cos\phi_o \cos\alpha_o \, d\phi$$

and letting $\phi_o = 0$ results in

$$(dY_b)_h = [\rho gAd\xi - gdm] \cos\alpha_o \, d\phi \qquad (27)$$

Control force is assumed to come from rudder deflection, and acts through the fin aerodynamic center.

$$\Delta C_{Y_c} = k_c \psi$$

$$(Y_c)_s = \rho \frac{U_o^2}{2} S_s k_c \psi \qquad (28)$$

5. Shear Force, Bending and Twisting Moment

The hull's shear force at station (l) is obtained by summing the sideforce values from the nose, up to (l):

$$S(l) = \int_0^l (dY)_h + \sum_{j=1}^{a} \left[(Y_g)_{T_j} + (Y_w)_{T_j} \right] \qquad (29)$$

where $(dY)_h = (dY_g)_h + (dY_w)_h + (dY_m)_h + (dY_b)_h$

and (a) is the number of rotors forward of station (l).

Likewise, the bending moment at (l), measured along the centerline, is

$$BM(l) = \int_0^l (l_{cm} - \xi)(dY)_h + \int_0^l (dN_m)_h + \sum_{j=1}^{a} (l - l_{T_j}) \left[(Y_g)_{T_j} + (Y_w)_{T_j} \right] \qquad (30)$$

Finally, the twisting moment at station (l) is

$$TM(l) = -\int_0^l h_{cm}(\xi)(dY)_h + \int_0^l (dL_m)_h + \int_0^l (dL_{mg})_h - \sum_{j=1}^{a} (h_{T_j}) \left[(Y_g)_{T_j} + (Y_w)_{T_j} \right] \qquad (31)$$

The term $(dL_{mg})_h$ is the torque contribution due to the center of gravity being offset from the central axis (see figure 7). It is calculated from

$$(dL_{mg})_h = h_{cm} g \, dm \, \phi \cos\alpha_o$$

B. FLIGHT DYNAMICS

1. Dynamic Stability

The equations for Lateral Dynamic Stability are taken from DeLaurier et. al. [Ref. 18] and given below:

$$\Delta C_{y_{aero}} + \Delta C_{y_c} - (\hat{B} - \hat{m}g) \cos\alpha_o \phi = 2\mu (D\beta + \hat{r}) \qquad (32)$$

$$\Delta C_{n_{aero}} + \Delta C_{n_c} - \hat{x}_b \hat{B} \cos\alpha_o \phi = I_{zz} D\hat{r} - I_{xz} D\hat{p} \tag{33}$$

$$\Delta C_{l_{aero}} + \Delta C_{l_c} + \hat{z}_b \hat{B} \cos\alpha_o \phi = I_{xx} D\hat{p} - I_{xz} D\hat{r} \tag{34}$$

$$D\phi = \hat{p} + \hat{r} \tan\alpha_o \tag{35}$$

$$D\psi = \hat{r} \sec\alpha_o \tag{36}$$

$$\Delta C_{Y_{aero}} = C_{Y_\beta}\beta + C_{Y_{\dot\beta}} D\beta + C_{Y_r}\hat{r} + C_{Y_{\dot r}} D\hat{r} + C_{Y_p}\hat{p} + C_{Y_{\dot p}} D\hat{p} \tag{37}$$

$$\Delta C_{n_{aero}} = C_{n_\beta}\beta + C_{n_{\dot\beta}} D\beta + C_{n_r}\hat{r} + C_{n_{\dot r}} D\hat{r} + C_{n_p}\hat{p} + C_{n_{\dot p}} D\hat{p} \tag{38}$$

$$\Delta C_{l_{aero}} = C_{l_\beta}\beta + C_{l_{\dot\beta}} D\beta + C_{l_r}\hat{r} + C_{l_{\dot r}} D\hat{r} + C_{l_p}\hat{p} + C_{l_{\dot p}} D\hat{p} \tag{39}$$

$$\Delta C_{Y_c} = k_c \psi \tag{40}$$

$$\Delta C_{n_c} = \frac{[l_s - l_{cm}]}{\bar{c}} \Delta C_{Y_c} = \frac{[l_s - l_{cm}]}{\bar{c}} k_c \psi \tag{41}$$

$$\Delta C_{l_c} = \frac{[h_s - h_{cm}]}{\bar{c}} \Delta C_{Y_c} = \frac{[h_s - h_{cm}]}{\bar{c}} k_c \psi \tag{42}$$

In this analysis $\beta = \frac{v}{U_o} = \hat{v}$, thus equations (32) to (39) become

$$\Delta C_{Y_{aero}} + \Delta C_{Y_c} - (\hat{B} - \hat{m}g) \cos\alpha_o \phi = 2\mu(D\hat{v} + \hat{r}) \tag{43}$$

$$\Delta C_{n_{aero}} + \Delta C_{n_c} - \hat{x}_b \hat{B} \cos\alpha_o \phi = I_{zz} D\hat{r} - I_{xz} D\hat{p} \tag{44}$$

$$\Delta C_{l_{aero}} + \Delta C_{l_c} - \hat{z}_b \hat{B} \cos\alpha_o \phi = I_{xx} D\hat{p} - I_{xz} D\hat{r} \tag{45}$$

$$D\phi = \hat{p} + \hat{r} \tan\alpha_o \tag{46}$$

$$D\psi = \hat{r} \sec\alpha_o \tag{47}$$

$$\Delta C_{Y_{aero}} = C_{Y_\beta}\hat{v} + C_{Y_{\dot\beta}}D\hat{v} + C_{Y_r}\hat{r} + C_{Y_{\dot r}}D\hat{r} + C_{Y_p}\hat{p} + C_{Y_{\dot p}}D\hat{p} \tag{48}$$

$$\Delta C_{n_{aero}} = C_{n_\beta}\hat{v} + C_{n_{\dot\beta}}D\hat{v} + C_{n_r}\hat{r} + C_{n_{\dot r}}D\hat{r} + C_{n_p}\hat{p} + C_{n_{\dot p}}D\hat{p} \tag{49}$$

$$\Delta C_{l_{aero}} = C_{l_\beta}\hat{v} + C_{l_{\dot\beta}}D\hat{v} + C_{l_r}\hat{r} + C_{l_{\dot r}}D\hat{r} + C_{l_p}\hat{p} + C_{l_{\dot p}}D\hat{p} \tag{50}$$

These equations are linear, and along with equations (40) through (42) can be written in matrix form as:

$$[\tilde{C}] \begin{bmatrix} \hat{v} \\ \hat{r} \\ \hat{p} \\ \hat{\phi} \\ \hat{\psi} \end{bmatrix} - [\tilde{D}] \begin{bmatrix} D\hat{v} \\ D\hat{r} \\ D\hat{p} \\ D\hat{\phi} \\ D\hat{\psi} \end{bmatrix} = 0$$

where: v is translation in the y-direction

r is the rotation rate about the z-axis

p is the rotation rate about the x-axis

ϕ is the roll angle

ψ is the yaw angle

The matrices $[\tilde{C}]$ and $[\tilde{D}]$ are given by

$$[\tilde{C}] = \begin{bmatrix} C_{Y_\beta} & (C_{Y_r}-2\mu) & C_{Y_p} & (\hat{m}g-\hat{B})\cos\alpha_o & -k_c \\ C_{n_\beta} & C_{n_r} & C_{n_p} & -\hat{x}_b\hat{B}\cos\alpha_o & \dfrac{(l_s-l_{cm})}{\bar{c}}k_c \\ C_{l_\beta} & C_{l_r} & C_{l_p} & -\hat{z}_b\hat{B}\cos\alpha_o & \dfrac{+h_{cm}}{\bar{c}}k_c \\ 0 & \tan\alpha_o & 1 & 0 & 0 \\ 0 & \sec\alpha_o & 0 & 0 & 0 \end{bmatrix}$$

$$[D] = \begin{bmatrix} (2\mu - C_{y_{\dot\beta}}) & -C_{y_{\dot r}} & -C_{y_{\dot p}} & 0 & 0 \\ -C_{n_{\dot\beta}} & (I_{zz} - C_{n_{\dot r}}) & -(I_{xz} + C_{n_{\dot p}}) & 0 & 0 \\ -C_{l_{\dot\beta}} & -(I_{xz} + C_{l_{\dot r}}) & (I_{xx} - C_{l_{\dot p}}) & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

To solve this system of equations, assume a solution of the form

$$\hat{v} = \hat{V} e^{i\hat{\sigma}\hat{t}} , \quad \hat{p} = \hat{P} e^{i\hat{\sigma}\hat{t}} , \quad \hat{r} = \hat{R} e^{i\hat{\sigma}\hat{t}}$$
$$\phi = \Phi e^{i\hat{\sigma}\hat{t}} , \quad \psi = \Psi e^{i\hat{\sigma}\hat{t}} \tag{52}$$

which, when substituted into equation (51) becomes

$$[\tilde{C} - i\hat{\sigma}\tilde{D}] \begin{bmatrix} \hat{V} \\ \hat{R} \\ \hat{P} \\ \Phi \\ \Psi \end{bmatrix} = 0 \tag{53}$$

where $\hat{\sigma}$ is the non-dimensional stability root. This is an eigenvalue problem. A computer solution is performed to find the eigenvalues (stability roots) and eigenvectors (model vectors) for the control gains considered. For the subsequent load-response analysis, dynamically stable cases must be chosen.

2. Turbulence Forcing Functions

As mentioned above, the model chosen for the turbulence is sinusoidal with Gaussian statistics, in particular,

$$\frac{v_g(\xi)}{U_o} = \Gamma \exp\left(i\omega t - i\omega\xi \frac{\cos\alpha_o}{U_o}\right) \tag{54}$$

By using this expression in equation (9), integrating from $\xi = 0$ to $\xi = l_h$ (the hull/fin intersection) and adding the contributions of the fins and thruster-rotor combinations, the complete turbulence forcing functions for the airship can be found. That is,

$$Y_g = \int_0^{l_h} d(Y_g)_h + \sum_{j=1}^{a} (Y_g)_{T_j} + (Y_g)_s \tag{55}$$

Likewise, the yawing moment about the nose is

$$N_{g_{nose}} = +\int_0^{l_h} \xi d(Y_g)_h + \sum_{j=1}^{a} \left[(l_T)_j (Y_g)_{T_j}\right] + l_s (Y_g)_s$$

and $$N_{g_{cm}} = N_{g_{nose}} - l_{cm} Y_g \tag{56}$$

and rolling moment is given by

$$L_g = -h_{cm} Y_g \tag{57}$$

These may be non-dimensionalized according to

$$Y_g = \frac{U_o^2}{2} S\, G_Y \qquad (L_g, N_g) = \frac{U_o^2}{2} S\bar{c}\, (G_l, G_n) \tag{58}$$

and the non-dimensional equations can be expressed as

$$G_y = G_{y_\gamma}\gamma \qquad G_l = G_{l_\gamma}\gamma \qquad G_n = G_{n_\gamma}\gamma \tag{59}$$

where $\gamma = \Gamma\exp(i\omega t) = \Gamma\exp(ik\hat{t})$ (60)

$$k = \frac{\bar{c}\omega}{2U_o}$$

G_{y_γ}, G_{l_γ} and G_{n_γ} are the turbulent forcing functions for the vehicle.

3. Motion Response Transfer Functions

Using the functions of equation (59) as forcing functions on the right-hand side of equation (53), and dividing through by γ gives

$$[\tilde{C} - ik\tilde{D}] \begin{bmatrix} \hat{V}/\Gamma \\ R/\Gamma \\ P/\Gamma \\ \Phi/\Gamma \\ \Psi/\Gamma \end{bmatrix} = \begin{bmatrix} G_{y_\gamma} \\ G_{n_\gamma} \\ G_{l_\gamma} \\ 0 \\ 0 \end{bmatrix} \tag{61}$$

Solution of this expression for specific reduced frequencies (k), or spectral wave numbers (Ω), and fixed stable control gains (k_c), allows calculation of the expressions necessary for the solution of distributed force loadings and moments, by means of the following expressions.

$$\hat{v} = \frac{v}{U_o} = \frac{\hat{V}}{\Gamma}\exp(ik\hat{t}), \qquad \frac{\bar{c}p}{2U_o} = \frac{\hat{P}}{\Gamma}\exp(ik\hat{t})$$

$$\frac{\bar{c}r}{2U_o} = \frac{\hat{R}}{\Gamma}\exp(ik\hat{t}), \qquad \phi = \frac{\Phi}{\Gamma}\exp(ik\hat{t}) \tag{62}$$

$$\psi = \frac{\Psi}{\Gamma}\exp(ik\hat{t})$$

C. LOAD RESPONSE TRANSFER FUNCTIONS

Once the motion response of the airship is known, the load response transfer functions can be calculated.

1. Turbulence Loading

These may be obtained by substituting equation 54 into equations (9) through (13) and dividing by γ (equation (60)). This gives, for example, for equation (9):

$$\frac{(dY_g)_h}{\Gamma} = \rho\frac{U_o^2}{2} K \frac{dA}{d\xi}\exp(-i\Omega\xi\cos\alpha_o)d\xi \tag{63}$$

where $\Omega = \frac{\omega}{U_o} = \frac{2k}{\bar{c}}$

Table II gives the complete list of load response transfer functions.

2. Motion Response Loading

The aerodynamic-reaction loading may be obtained by replacing the motion variables, $\left(\frac{v}{U_o}\right)$, $\left(\frac{\bar{c}p}{2U_o}\right)$, etc., in equations (14) through (20) with the corresponding motion-response transfer functions in equations (62). For example, equation (14) becomes

$$\frac{(dY_w)_h}{\Gamma} = \{\rho \frac{U_o^2}{2} K \frac{dA}{d\xi} \left[\frac{\hat{V}}{\Gamma} - \frac{2}{\bar{c}} (l_{cm} - \xi) \frac{\hat{R}}{\Gamma} \right]$$

$$+ \rho U_o^2 A \{ i\Omega \left[\frac{\hat{V}}{\Gamma} - \frac{2}{\bar{c}} \frac{\hat{R}}{\Gamma} (l_{cm} - \xi) \right] k_2 + \frac{2}{\bar{c}} \frac{\hat{R}}{\Gamma} k_1 \} \} d\xi \tag{64}$$

The Inertial-Reaction, and Bouyancy loading transfer functions are similarly obtained from equations (21) through (27). For example, equation (21) becomes

$$\frac{(dY_m)_h}{\Gamma} = \{ - \frac{2U_o^2}{\bar{c}} \frac{\hat{R}}{\Gamma} + i\Omega U_o^2 \left[\frac{\hat{V}}{\Gamma} - \frac{2}{\bar{c}} \frac{\hat{R}}{\Gamma} (l_{cm} - \xi) \right] \} dm \tag{65}$$

and equation (27) becomes

$$\frac{(dY_B)_h}{\Gamma} = [\rho g A d\xi - g dm] \cos\alpha_o \frac{\Phi}{\Gamma} \tag{66}$$

3. <u>Shear Force, Bending and Twisting Moment Transfer Functions</u>

The shear force loading transfer function is obtained using equation (29):

$$\frac{S(l)}{\Gamma} = \int_0^l \frac{dY}{\Gamma} + \sum_{j=1}^{a} \frac{(Y_T)_j}{\Gamma} \tag{67}$$

where:

$$\frac{dY}{\Gamma} = \frac{(dY_g)_h}{\Gamma} + \frac{(dY_w)_h}{\Gamma} + \frac{(dY_m)_h}{\Gamma} + \frac{(dY_B)_h}{\Gamma}$$

and

$$\frac{(Y_T)_j}{\Gamma} = \frac{(Y_g)_{T_j}}{\Gamma} + \frac{(Y_w)_{T_j}}{\Gamma}$$

The bending-moment transfer function comes from equation (30)

$$\frac{BM(l)}{\Gamma} = \int_0^l (l_{cm}-\xi)\frac{(dY)_h}{\Gamma} + \int_0^l \frac{(dN_m)_h}{\Gamma} + \sum_{j=1}^{a} (l-l_{T_j})\left[\frac{(Y_g)_{T_j}}{\Gamma} + \frac{(Y_w)_{T_j}}{\Gamma}\right] \tag{68}$$

and finally the twisting-moment transfer function, from equation (31), is:

$$\frac{TM(l)}{\Gamma} = -\int_0^l h_{cm}(\xi)(dY)_h + \int_0^l \frac{(dL_m)_h}{\Gamma} + \int_0^l \frac{(dL_{mg})_h}{\Gamma} - \sum_{j=1}^{a} h_{T_j}\left[\frac{(Y_g)_{T_j}}{\Gamma} + \frac{(Y_w)_{T_j}}{\Gamma}\right] \tag{69}$$

An important check on the analytical model is obtained by ensuring the net Shear Force, and Bending and Twisting Moments equal zero.

$$\frac{S(l)_h}{\Gamma} + \frac{(Y_g)_s}{\Gamma} + \frac{(Y_w)_s}{\Gamma} + \frac{(Y_m)_s}{\Gamma} + \frac{(Y_c)_s}{\Gamma} = 0 \tag{70}$$

The moments are evaluated to the empennage assembly's mass center, $(l_{cm})_s$, so that

$$\frac{BM(l_{cm})_s}{\Gamma} + [(l_{cm})_s - l_s]\left[\frac{(Y_g)_s}{\Gamma} + \frac{(Y_w)_s}{\Gamma} + \frac{(Y_c)_s}{\Gamma}\right] + \frac{(N_w)_s}{\Gamma} + \frac{(N_m)_s}{\Gamma} = 0 \tag{71}$$

$$\frac{TM(l_{cm})_s}{\Gamma} + \frac{(L_w)_s}{\Gamma} + \frac{(L_m)_s}{\Gamma} + (h_{cm})_s\left[\frac{(Y_g)_s}{\Gamma} + \frac{(Y_w)_s}{\Gamma} + \frac{(Y_c)_s}{\Gamma}\right] = 0 \tag{72}$$

These equations may be non-dimensionalized as follows:

$$\frac{C_s(l)}{\Gamma} = \frac{2}{\rho U_o^{\,2} S}\,\frac{S(l)}{\Gamma} \tag{73}$$

$$\frac{C_{BM}(l)}{\Gamma} = \frac{2}{\rho U_o^{\,2} S\bar{c}}\,\frac{BM(l)}{\Gamma} \tag{74}$$

$$\frac{C_{TM}(l)}{\Gamma} = \frac{2}{\rho U_o^{\,2} S\bar{c}}\,\frac{TM(l)}{\Gamma} \tag{75}$$

D. RESPONSE TO ATMOSPHERIC TURBULENCE

Once the force and moment transfer function coefficients are known, the turbulence statistics can be applied to obtain estimates of airship lifetime and failure probability. When dealing with the lateral aerodynamic case, two different spectra must be considered--Φ_{11} and Φ_{22}. This analysis will use the von Kàrmàn spectra as given by equations (7) and (6) respectively. As explained in Chapter II, the first is used when the flight direction is perpendicular to the mean wind, and the second when the direction is parallel.

1. Root-Mean-Square Responses

The root-mean-square response to turbulence of any system parameter can be obtained using its transfer function

multiplied by the spectrum (provided, of course, the spectrum is Gaussian). For example, the rms shear force coefficient is

$$\frac{(C_s)_{rms}}{\sigma} = \left[\frac{2}{U_o^{\,2}} \int_0^\infty \left|\frac{C_s}{\Gamma}\right|^2 \frac{\Phi_{ii}}{\sigma^2}\, d\Omega\right]^{1/2} \tag{76}$$

Response to various conditions can be evaluated using appropriate values for σ and L in the equations for Φ_{ii}, and choosing either Φ_{11} or Φ_{22} according to desired flight direction.

2. Mission Analysis Method

The mission analysis method is a technique for estimating a flight vehicle's probable lifetime. The method is based on the probability distribution of encountering turbulence in representative flight operations [Refs. 7 and 15]. It is assumed the total flight is a sum of Gaussian patches [Ref. 2]. The formula for calculating the number of exceedences is

$$N(x) = \sum tN_o \left[p_1 \exp\left(\frac{-|x-x_{ref}|}{b_1\bar{A}}\right) + p_2 \exp\left(\frac{-|x-x_{ref}|}{b_2\bar{A}}\right)\right] \tag{77}$$

where: x = maximum structural value of bending, moment coefficient at a given station,

x_{ref} = value of x in one-g level flight,

$N(x)$ = average number of exceedences of the indicated value of x per unit time

N_o = number of zero crossings of x per unit time

$\bar{A}$ = $[(C_{BM})_{rms}/\sigma]/\gamma_{rms}$

t = fraction of time in mission segment

p_1, p_2 = probability values from Table I

b_1, b_2 = intensity levels from Table I

also

$$N_o = \left[\frac{1}{2\pi}\,\frac{(\dot{BM})_{ms}}{(BM)_{ms}}\right]^{1/2}$$

where

$$(BM)_{ms} = \left(\frac{\rho U_o{}^2 S\bar{c}}{2}\right)^2 \int_0^\infty \left|\frac{C_{BM}}{\Gamma}\right| \Phi_{ii}\, d\Omega \qquad (78)$$

$$(\dot{BM})_{ms} = \left(\frac{\rho U_o{}^2 S\bar{c}}{2}\right)^2 \int_0^\infty \left|\frac{C_{BM}}{\Gamma}\right| \Omega\Phi_{ii}\, d\Omega \qquad (79)$$

The probable lifetime is then $[N(x)]^{-1}$

Shear force and twisting moment are analyzed in the same fashion using the appropriate transfer functions.

3. Other Methods

DeLaurier and Hui [Ref. 5] also include Failure-Probability analysis [Ref. 3] and "Mil-Spec Storm" analysis in their paper. There are others in existence, such as the Design Envelope Analysis [Ref. 7] that have been used for HTA flight, and are well documented. Because of this, they will not be included here, as techniques for using them are

the same once the transfer functions of response are known. The exact method used is up to the designer, based on his needs.

IV. NUMERICAL EXAMPLE

In order to illustrate the lateral aerodynamic case developed in Chapter III, an example using the USS AKRON (ZR-4) is presented. The flight conditions chosen are:

$$U_o = 123 \text{ ft/sec}$$

$$\text{Alt} = 1000 \text{ ft}$$

The velocity represents the maximum for the vehicle, and the altitude is typical of its operational range. In addition, a condition of neutral buoyancy (B-mg = 0.0) was selected. The geometry was taken from Freeman [Ref. 19] and the weight distribution from Woodward [Ref. 20]. With this information available, the inertial properties of the AKRON could be calculated using the method of Scholaert and DeLaurier [Ref. 21] (see Appendix). The values obtained are shown in Table III. The Hull cross-flow and stabilizer efficiency factors are calculated using the method given in reference 6, and are:

$$K = 0.93225$$

$$\eta_s = 0.2600$$

The apparent-mass coefficients are from Munk [Ref. 22].

The stability derivatives are taken from DeLaurier and Schenck [Ref. 18], and shown in Table IV. With these, the control gain, and the inertial and geometrical properties,

equation 53 can be solved to find the stable roots. This was done in reference 18 and the results are shown in figure 8. Mode 4 (indicated in the figure) is characterized by roll, yaw, and sideslip of equal magnitudes not unlike the dutch roll mode of a fixed wing aircraft. Mode 5 is one of equal and opposite β and ψ motions with small ϕ perturbations. Mode 6 is a relatively high-frequency rolling motion, little affected by control gain. Modes 1, 2, and 3 refer to longitudinal aerodynamic modes [Ref. 18]. From this analysis, a control gain of 0.2 was found to provide the minimum stable condition.

The forcing functions were next obtained using equations 54 through 60, and are plotted in figure 9. The peaks in all the curves occur at a wave number of about .008. This corresponds to a wavelength equal to the length of the airship. $|G_{l_\gamma}|$ is significantly smaller than the others, as expected, due to the smaller moment arm through which the sideforce works in producing roll.

With the turbulence forcing functions, equation 61 was solved to obtain the motion response transfer functions. These are shown in figures 10 through 14. Control gains of 0.2, 1.0, and 2.0 were used to illustrate the effect of its variation. The most significant feature of these responses is the peak at a wave number of .008. This corresponds, as in the forcing functions, to a condition where the spectral component wavelength exactly equals the airship length. This

is the result predicted by Calligeros and McDavitt [Ref. 4] for the longitudinal case. DeLaurier and Hui [Ref. 5] also obtained this result, but only for cases of higher control gain. For the lateral case, the control gain does not significantly change this peak, although, for yaw and yaw rate (ψ and γ), and to a lesser extent roll (ϕ), the response at lower wave numbers is reduced.

Finally, the load response transfer functions were calculated. The results are shown in figures 15 through 17 for a wave number of .009, and a control gain of 0.2. Complete results are given in the appendix. For the most part, the results yield no surprises. The magnitudes of the load response follow the general trend of the combined motion responses, thus the peak loads occur at wave numbers near .008. The location along the axis of the peak load varies as the magnitude of the motions increases, shifting aft in the case of shear and twisting moment, and to the center for bending moment. Again, the lack of significant change with control gain is apparent.

V. CONCLUSIONS AND RECOMMENDATIONS

The analysis presented is an extension of the work by DeLaurier and Hui [Ref. 5], and is subject to the same restrictions. That is, it is limited to small perturbations in order to allow a linear analysis usable with power spectral methods, and its ability to make precise predictions of the loading when used with one of the methods that accounts for severe turbulence is questionable. Nonetheless, it is a valuable tool in understanding the response to an initial disturbance, and when employed as the aerodynamic input to the various statistical methods discussed earlier, it can yield important design and operational insight.

The limited effectiveness of the simple control model employed, which is typical of someone cuing his response to a compass, was demonstrated. It is suggested that an examination of the effects of roll control and yaw rate feedback be made. This would allow a decision as to the feasibility of using control to provide gust alleviation. As discussed by DeLaurier and Hui, control gain made a large difference in the expected lifetime of an airship when considering only longitudinal aerodynamics. Undoubtedly, for the lateral case, even the yaw control used in this analysis will contribute to increased survivability due to the reduction of loads at low wave numbers. Thus, the next step is to employ

the statistical methods to discover how much change is realized.

The case of combined longitudinal and lateral motion needs to be studied. No aircraft ever built has ever managed to fly through turbulence that is strictly one dimensional, as is assumed for this analysis. Coupling the two cases would give a much better idea of the true action of an airship in turbulence.

Finally, some means must be found to establish the veracity of this model, as well as that for the longitudinal case. To the author's knowledge, no investigation of the actual response of an airship to conditions of known turbulence has ever been made. This is, of course, a difficult project, considering the limited number of airships currently available if full scale tests are to be carried out. Wind tunnel investigations, made in the various oscillating flow tunnels available, would be helpful. Until some tests are done, however, this type of analysis must be considered only for its qualitative aspects as opposed to its quantitative predictions.

COMPUTER OUTPUT FOR THE NUMERICAL EXAMPLE

```
CONTROL GAIN = 0.20
WAVE NUMBER =.1000OE-04

THE FORCING FUNCTION MAGNITUDES ARE:
         GY           GN           GL
     .61066E+00   .66185E+00   .29296E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
      SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
     .19540E+01   .15717E-01   .54070E-03   .12302E+00   .40043E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
          STATION             CS               CBM              CTM
         78.500000         0.652803         0.237232         0.000000
        157.000000         1.081468         0.283407         0.015538
        235.500000         1.204353         0.191262         0.020323
        314.000000         1.209334         0.064002         0.018993
        392.500000         1.156551         0.065707         0.014817
        510.250000         0.940412         0.220875         0.002184
        605.959961         0.572192         0.244691         0.019989


CONTROL GAIN = 0.20
WAVE NUMBER =.20000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
         GY           GN           GL
     .61056E+00   .66184E+00   .29291E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
      SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
     .19538E+01   .31421E-01   .10971E-02   .12528E+00   .40027E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
          STATION             CS               CBM              CTM
         78.500000         0.653393         0.237455         0.000000
        157.000000         1.082489         0.283722         0.015564
        235.500000         1.205780         0.191651         0.020402
        314.000000         1.211145         0.064651         0.019150
        392.500000         1.158874         0.065860         0.015139
        510.250000         0.943718         0.220797         0.004343
        605.959961         0.577579         0.244644         0.020353
```

```
CONTROL GAIN = 0.20
WAVE NUMBER =.30000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
         GY             GN             GL
      .61046E+00    .66184E+00    .29287E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP      YAW RATE      ROLL RATE       ROLL          YAW
      .19535E+01    .47101E-01    .16843E-02    .12894E+00    .40001E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
           STATION              CS              CBM             CTM
           78.500000         0.654447        0.237852        0.000000
          157.000000         1.084311        0.284278        0.015608
          235.500000         1.208291        0.192318        0.020535
          314.000000         1.214296        0.065726        0.019412
          392.500000         1.162869        0.066119        0.015661
          510.250000         0.949313        0.220692        0.006504
          605.959961         0.586508        0.244593        0.020944


CONTROL GAIN = 0.20
WAVE NUMBER =.40000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
         GY             GN             GL
      .61036E+00    .66186E+00    .29282E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP      YAW RATE      ROLL RATE       ROLL          YAW
      .19531E+01    .62746E-01    .23157E-02    .13388E+00    .39966E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
           STATION              CS              CBM             CTM
           78.500000         0.655960        0.238421        0.000000
          157.000000         1.086925        0.285072        0.015670
          235.500000         1.211873        0.193260        0.020720
          314.000000         1.218767        0.067202        0.019774
          392.500000         1.168507        0.066482        0.016363
          510.250000         0.957137        0.220558        0.008660
          605.959961         0.598789        0.244538        0.021742
```

```
CONTROL GAIN = 0.20
WAVE NUMBER =.50000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
         GY          GN          GL
   .61026E+00  .66189E+00  .29277E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP     YAW RATE    ROLL RATE      ROLL          YAW
   .19526E+01  .78343E-01  .30029E-02  .13995E+00  .39920E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
          STATION           CS             CBM            CTM
        78.500000        0.657923        0.239159        0.000000
       157.000000        1.090310        0.286098        0.015750
       235.500000        1.216497        0.194467        0.020956
       314.000000        1.224521        0.069048        0.020228
       392.500000        1.175735        0.066944        0.017220
       510.250000        0.967100        0.220397        0.010807
       605.959961        0.614170        0.244479        0.022722


CONTROL GAIN = 0.20
WAVE NUMBER =.60000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
         GY          GN          GL
   .61015E+00  .66194E+00  .29272E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP     YAW RATE    ROLL RATE      ROLL          YAW
   .19521E+01  .93881E-01  .37551E-02  .14699E+00  .39865E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
          STATION           CS             CBM            CTM
        78.500000        0.660323        0.240060        0.000000
       157.000000        1.094449        0.287350        0.015848
       235.500000        1.222136        0.195931        0.021239
       314.000000        1.231519        0.071226        0.020766
       392.500000        1.184502        0.067502        0.018207
       510.250000        0.979101        0.220209        0.012944
       605.959961        0.632365        0.244416        0.023858
```

CONTROL GAIN = 0.20
WAVE NUMBER =.70000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61005E+00	.66201E+00	.29267E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19516E+01	.10935E+00	.45800E-02	.15485E+00	.39800E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.663145	0.241120	0.000000
157.000000	1.099314	0.288819	0.015962
235.500000	1.228750	0.197639	0.021567
314.000000	1.239710	0.073701	0.021381
392.500000	1.194729	0.068151	0.019301
510.250000	0.993011	0.219994	0.015068
605.959961	0.653064	0.244349	0.025124

CONTROL GAIN = 0.20
WAVE NUMBER =.80000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60994E+00	.66208E+00	.29261E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19510E+01	.12474E+00	.54829E-02	.16337E+00	.39726E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.666369	0.242331	0.000000
157.000000	1.104870	0.290496	0.016092
235.500000	1.236292	0.199578	0.021937
314.000000	1.249031	0.076432	0.022063
392.500000	1.206339	0.068887	0.020480
510.250000	1.008696	0.219753	0.017177
605.959961	0.675955	0.244279	0.026497

CONTROL GAIN = 0.20
WAVE NUMBER =.50000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60983E+00	.66218E+00	.29256E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19503E+01	.14003E+00	.64678E-02	.17244E+00	.39642E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.669978	0.243686	0.000000
157.000000	1.111086	0.292369	0.016236
235.500000	1.244714	0.201732	0.022344
314.000000	1.259421	0.079383	0.022804
392.500000	1.219241	0.069702	0.021726
510.250000	1.026006	0.219486	0.019269
605.959961	0.700730	0.244206	0.027957

CONTROL GAIN = 0.20
WAVE NUMBER =.10000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60972E+00	.66229E+00	.29251E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19496E+01	.15523E+00	.75374E-02	.18194E+00	.39549E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.673948	0.245176	0.000000
157.000000	1.117921	0.294426	0.016394
235.500000	1.253960	0.204087	0.022786
314.000000	1.270804	0.082520	0.023595
392.500000	1.233339	0.070591	0.023023
510.250000	1.044790	0.219194	0.021342
605.959961	0.727099	0.244129	0.029485

CONTROL GAIN = 0.20
WAVE NUMBER =.20000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60855E+00	.66422E+00	.29195E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19396E+01	.29970E+00	.22914E-01	.28566E+00	.38178E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.727811	0.265368	0.000000
157.000000	1.210469	0.322141	0.018487
235.500000	1.378057	0.234921	0.028313
314.000000	1.422009	0.118367	0.032822
392.500000	1.417681	0.082189	0.036798
510.250000	1.281152	0.215064	0.040642
605.959961	1.029990	0.243208	0.046034

CONTROL GAIN = 0.20
WAVE NUMBER =.30000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60734E+00	.66763E+00	.29137E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19256E+01	.42633E+00	.45602E-01	.38288E+00	.36207E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.789513	0.288476	0.000001
157.000000	1.316072	0.353618	0.020810
235.500000	1.518108	0.268751	0.034044
314.000000	1.590379	0.152318	0.041716
392.500000	1.618807	0.095028	0.049079
510.250000	1.527111	0.209329	0.056514
605.959961	1.316590	0.242043	0.061165

```
CONTROL GAIN = 0.20
WAVE NUMBER =.40000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
        GY           GN           GL
   .60611E+00   .67249E+00   .29078E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
   .19087E+01   .53291E+00   .73201E-01   .46283E+00   .33943E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
           STATION              CS              CBM              CTM
          78.500000          0.840595         0.307626         0.000001
         157.000000          1.403069         0.379664         0.022717
         235.500000          1.633134         0.296545         0.038635
         314.000000          1.728057         0.178739         0.048663
         392.500000          1.781960         0.105961         0.058465
         510.250000          1.722820         0.202840         0.068494
         605.959961          1.536736         0.240689         0.073059

CONTROL GAIN = 0.20
WAVE NUMBER =.50000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
        GY           GN           GL
   .60491E+00   .67875E+00   .29020E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
   .18898E+01   .62081E+00   .10357E+00   .52488E+00   .31634E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
           STATION              CS              CBM              CTM
          78.500000          0.873510         0.320029         0.000002
         157.000000          1.458610         0.396683         0.023977
         235.500000          1.707350         0.315360         0.041749
         314.000000          1.817780         0.196917         0.053408
         392.500000          1.889241         0.113992         0.064909
         510.250000          1.852855         0.196245         0.076836
         605.959961          1.683661         0.239225         0.081617
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```
CONTROL GAIN = 0.20
WAVE NUMBER =.60000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
           GY           GN           GL
      .60375E+00   .68635E+00   .28965E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP     YAW RATE     ROLL RATE       ROLL          YAW
      .18694E+01   .69318E+00   .13524E+00   .57175E+00   .29435E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
           STATION              CS              CBM              CTM
          78.500000          0.888033         0.325615         0.000004
         157.000000          1.482316         0.404643         0.024602
         235.500000          1.740728         0.325507         0.043496
         314.000000          1.860188         0.207907         0.056206
         392.500000          1.942540         0.119234         0.068839
         510.250000          1.921973         0.189938         0.082156
         605.959961          1.766445         0.237748         0.087329


CONTROL GAIN = 0.20
WAVE NUMBER =.70000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
           GY           GN           GL
      .60266E+00   .69521E+00   .28912E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP     YAW RATE     ROLL RATE       ROLL          YAW
      .18478E+01   .75345E+00   .16742E+00   .60702E+00   .27423E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
           STATION              CS              CBM              CTM
          78.500000          0.887216         0.325521         0.000006
         157.000000          1.479346         0.405048         0.024697
         235.500000          1.739951         0.328543         0.044133
         314.000000          1.863228         0.213262         0.057460
         392.500000          1.951330         0.122217         0.070810
         510.250000          1.941836         0.184104         0.085158
         605.959961          1.798752         0.236359         0.090837
```

CONTROL GAIN = 0.20
WAVE NUMBER =.80000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60166E+00	.70527E+00	.28864E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.18251E+01	.80462E+00	.19978E+00	.63402E+00	.25625E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.874949	0.321186	0.000008
157.000000	1.456253	0.399770	0.024388
235.500000	1.713269	0.326251	0.043937
314.000000	1.836377	0.214491	0.057567
392.500000	1.926462	0.123539	0.071345
510.250000	1.924844	0.178798	0.086482
605.959961	1.793912	0.235136	0.092751

CONTROL GAIN = 0.20
WAVE NUMBER =.90000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60075E+00	.71644E+00	.28821E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.18015E+01	.84905E+00	.23233E+00	.65550E+00	.24035E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.854832	0.313945	0.000010
157.000000	1.419082	0.390524	0.023789
235.500000	1.668203	0.320211	0.043145
314.000000	1.788183	0.212848	0.056866
392.500000	1.877569	0.123736	0.070879
510.250000	1.881737	0.174014	0.086654
605.959961	1.763109	0.234134	0.093574

CONTROL GAIN = 0.20
WAVE NUMBER =.10000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.59997E+00	.72864E+00	.28783E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.17769E+01	.88846E+00	.26523E+00	.67357E+00	.22636E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.829797	0.304882	0.000013
157.000000	1.372738	0.378694	0.022990
235.500000	1.610818	0.311679	0.041945
314.000000	1.725497	0.209305	0.055622
392.500000	1.812331	0.123233	0.069755
510.250000	1.820993	0.169710	0.086085
605.959961	1.715072	0.233374	0.093695

CONTROL GAIN = 0.20
WAVE NUMBER =.20000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60042E+00	.88883E+00	.28805E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.14790E+01	.11447E+01	.67587E+00	.85850E+00	.14582E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.586978	0.216714	0.000065
157.000000	0.865587	0.248165	0.012625
235.500000	0.924737	0.205288	0.026839
314.000000	0.944674	0.157462	0.041608
392.500000	0.993928	0.120535	0.058528
510.250000	1.073725	0.145735	0.081325
605.959961	1.146722	0.232768	0.094352

```
CONTROL GAIN = 0.20
WAVE NUMBER =.30000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
          GY             GN             GL
      .61712E+00   .10700E+01   .29606E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
      .11003E+01   .12024E+01   .13867E+01   .11755E+01   .10212E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
           STATION             CS             CBM            CTM
          78.500000         0.497046       0.184123       0.000200
         157.000000         0.538568       0.165723       0.005468
         235.500000         0.367343       0.125053       0.029085
         314.000000         0.419372       0.132322       0.055028
         392.500000         0.689627       0.149338       0.081781
         510.250000         1.089929       0.151987       0.113898
         605.959961         1.358668       0.217797       0.125510


CONTROL GAIN = 0.20
WAVE NUMBER =.40000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
          GY             GN             GL
      .64448E+00   .12258E+01   .30919E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
      .67565E+00   .10358E+01   .25474E+01   .16211E+01   .65974E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
           STATION             CS             CBM            CTM
          78.500000         0.434833       0.160260       0.000491
         157.000000         0.292965       0.092671       0.008731
         235.500000         0.240585       0.081765       0.045973
         314.000000         0.836513       0.169587       0.086100
         392.500000         1.437812       0.221642       0.127013
         510.250000         2.141464       0.186965       0.175656
         605.959961         2.478434       0.166207       0.190058
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CONTROL GAIN = 0.20
WAVE NUMBER =.50000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
           GY           GN           GL
      .67258E+00   .13310E+01   .32267E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
        SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
      .24526E+00   .67855E+00   .43429E+01   .22125E+01   .34576E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
            STATION              CS              CBM              CTM
           78.500000          0.266768        0.094702         0.001046
          157.000000          0.189725        0.024270         0.014957
          235.500000          0.863461        0.209193         0.064239
          314.000000          1.753875        0.341996         0.120351
          392.500000          2.703362        0.387143         0.180007
          510.250000          3.844154        0.246157         0.257894
          605.959961          4.324980        0.071187         0.290179


CONTROL GAIN = 0.20
WAVE NUMBER =.60000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
           GY           GN           GL
      .69215E+00   .13729E+01   .33206E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
        SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
      .38654E+00   .71525E+00   .72023E+01   .30592E+01   .30372E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
            STATION              CS              CBM              CTM
           78.500000          0.184072        0.069484         0.002081
          157.000000          0.778218        0.250753         0.020564
          235.500000          1.826513        0.523120         0.080676
          314.000000          3.118036        0.718689         0.155355
          392.500000          4.585062        0.741300         0.240635
          510.250000          6.445200        0.355100         0.368677
          605.959961          7.238190        0.165356         0.445685
```

CONTROL GAIN = 0.20
WAVE NUMBER =.70000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.69712E+00	.13477E+01	.33444E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.11008E+01	.20909E+01	.12345E+02	.44961E+01	.76104E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	1.149822	0.438929	0.004162
157.000000	2.162449	0.736564	0.026533
235.500000	3.621204	1.172613	0.097797
314.000000	5.498711	1.497783	0.197320
392.500000	7.808969	1.497262	0.321883
510.250000	10.938520	0.614341	0.541721
605.959961	12.396368	0.558990	0.719025

CONTROL GAIN = 0.20
WAVE NUMBER =.80000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.68519E+00	.12592E+01	.32872E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.22778E+01	.50936E+01	.22118E+02	.70498E+01	.16222E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	3.452179	1.305918	0.008521
157.000000	5.377102	1.840727	0.036940
235.500000	7.396248	2.571503	0.125860
314.000000	10.074638	3.136181	0.257785
392.500000	13.690218	3.110294	0.436685
510.250000	19.039459	1.250183	0.819951
605.959961	21.936630	1.387006	1.220056

CONTROL GAIN = 0.20
WAVE NUMBER =.90000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.65749E+00	.11188E+01	.31543E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.22280E+01	.58179E+01	.21336E+02	.60459E+01	.16470E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	4.577765	1.719222	0.009247
157.000000	6.748293	2.279095	0.040418
235.500000	8.234304	2.932747	0.121645
314.000000	10.067587	3.427219	0.217082
392.500000	12.753042	3.388912	0.328918
510.250000	17.369659	1.439411	0.649486
605.959961	20.566772	1.623383	1.111805

CONTROL GAIN = 0.20
WAVE NUMBER =.10000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61780E+00	.94575E+00	.29639E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.11559E+01	.35247E+01	.11758E+02	.29989E+01	.89803E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	3.132074	1.167065	0.005662
157.000000	4.656887	1.532093	0.036617
235.500000	5.339117	1.868261	0.093290
314.000000	5.927462	2.083221	0.150272
392.500000	6.762783	2.041378	0.181123
510.250000	6.673275	0.947996	0.282001
605.959961	10.728956	1.013124	0.571219

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CONTROL GAIN = 0.20
WAVE NUMBER =.20000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
       GY          GN          GL
   .29315E+00  .88392E+00  .14066E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP    YAW RATE    ROLL RATE      ROLL          YAW
   .16034E+00  .87746E+00  .21816E+01  .27832E+00  .11178E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
         STATION            CS            CBM            CTM
         78.500000       1.152570       0.435841       0.002101
        157.000000       1.037697       0.425607       0.045206
        235.500000       0.372270       0.355253       0.112517
        314.000000       1.616535       0.697160       0.104482
        392.500000       2.841013       0.697531       0.028231
        510.250000       2.182358       0.394427       0.088081
        605.959961       1.715158       0.358596       0.071413


CONTROL GAIN = 0.20
WAVE NUMBER =.30000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
       GY          GN          GL
   .10961E+00  .74178E+00  .52583E-02

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP    YAW RATE    ROLL RATE      ROLL          YAW
   .71773E-01  .46384E+00  .11081E+01  .94253E-01  .39393E-01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
         STATION            CS            CBM            CTM
         78.500000       0.748360       0.290370       0.001601
        157.000000       0.812885       0.102953       0.077025
        235.500000       1.730423       0.519041       0.080930
        314.000000       1.728717       0.584548       0.052577
        392.500000       0.488448       0.597263       0.109876
        510.250000       2.383591       0.154667       0.065140
        605.959961       0.715195       0.224979       0.049563
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CONTROL GAIN = 0.20
WAVE NUMBER =.40000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.24458E+00	.63639E+00	.11734E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.43419E-01	.29349E+00	.69482E+00	.44325E-01	.18693E-01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.576646	0.218671	0.001338
157.000000	1.285373	0.332782	0.075660
235.500000	1.410335	0.443433	0.057990
314.000000	1.233570	0.414013	0.084400
392.500000	1.852176	0.434170	0.074062
510.250000	2.035723	0.108184	0.050662
605.959961	0.354131	0.151072	0.027899

CONTROL GAIN = 0.20
WAVE NUMBER =.50000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.36215E+00	.52871E+00	.17374E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.29050E-01	.19377E+00	.45932E+00	.23442E-01	.98739E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.587016	0.207608	0.001106
157.000000	1.310920	0.425263	0.056533
235.500000	1.107309	0.129982	0.090728
314.000000	1.598883	0.393697	0.063408
392.500000	1.544329	0.349059	0.058971
510.250000	1.188884	0.242864	0.049124
605.959961	0.284102	0.090750	0.008276

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CONTROL GAIN = 0.20
WAVE NUMBER =.60000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
         GY           GN           GL
     .51347E+00   .45648E+00   .24634E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
      SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
     .24138E-01   .13695E+00   .31873E+00   .13556E-01   .58151E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
            STATION            CS              CBM              CTM
           78.500000        0.643571        0.223922        0.000921
          157.000000        1.160521        0.337170        0.048571
          235.500000        1.550056        0.437335        0.079754
          314.000000        1.145030        0.296267        0.071790
          392.500000        1.010427        0.366862        0.068022
          510.250000        0.337443        0.314961        0.033967
          605.999961        0.558483        0.026738        0.035750


CONTROL GAIN = 0.20
WAVE NUMBER =.70000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
         GY           GN           GL
     .65821E+00   .39145E+00   .31577E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
      SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
     .22010E-01   .97028E-01   .21375E+00   .77927E-02   .35315E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
            STATION            CS              CBM              CTM
           78.500000        0.672918        0.236757        0.000721
          157.000000        1.041965        0.221562        0.037318
          235.500000        1.340559        0.249585        0.079496
          314.000000        1.740253        0.331336        0.107676
          392.500000        1.999074        0.242040        0.116080
          510.250000        1.334963        0.277302        0.090895
          605.999961        0.910286        0.058236        0.083215
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CONTROL GAIN = 0.20
WAVE NUMBER =.80000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
          GY            GN            GL
      .70105E+00   .40424E+00   .33632E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
        SIDESLIP      YAW RATE     ROLL RATE       ROLL          YAW
      .20873E-01   .85286E-01   .17442E+00   .55645E-02   .27161E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
            STATION               CS                 CBM                CTM
           78.500000           0.710734           0.255827           0.000672
          157.000000           1.119813           0.286351           0.016939
          235.500000           1.157440           0.231112           0.019265
          314.000000           1.079324           0.271900           0.014292
          392.500000           0.967588           0.333952           0.007460
          510.250000           2.056246           0.174401           0.157102
          605.959961           1.063324           0.109369           0.126323


CONTROL GAIN = 0.20
WAVE NUMBER =.90000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
          GY            GN            GL
      .83025E+00   .53478E+00   .39831E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
        SIDESLIP      YAW RATE     ROLL RATE       ROLL          YAW
      .23686E-01   .99234E-01   .19241E+00   .54571E-02   .28092E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
            STATION               CS                 CBM                CTM
           78.500000           0.768450           0.286531           0.000834
          157.000000           1.375266           0.444614           0.028224
          235.500000           1.737722           0.497728           0.073297
          314.000000           1.772990           0.438384           0.107678
          392.500000           1.406926           0.438248           0.119724
          510.250000           2.505047           0.058959           0.097379
          605.959961           1.279762           0.154907           0.094539
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CONTROL GAIN = 0.20
WAVE NUMBER =.10000E+00

THE FORCING FUNCTION MAGNITUDES ARE:
        GY           GN           GL
   .12195E+01   .85951E+00   .58506E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP     YAW RATE    ROLL RATE       ROLL          YAW
   .32743E-01   .14379E+00   .27641E+00   .70559E-02   .36635E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
        STATION             CS            CBM            CTM
       78.500000        0.807979       0.313998       0.001331
      157.000000        1.177783       0.391707       0.054202
      235.500000        0.618283       0.264058       0.100733
      314.000000        1.561124       0.636597       0.082167
      392.500000        2.850967       0.620091       0.054767
      510.250000        2.842363       0.231886       0.080716
      605.959961        2.087214       0.308157       0.115052
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CONTROL GAIN = 1.00
WAVE NUMBER =.10000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
        GY          GN          GL
    .61066E+00  .66185E+00  .29296E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
      SIDESLIP    YAW RATE    ROLL RATE     ROLL         YAW
    .19540E+01  .31438E-02  .49158E-03  .12228E+00  .80097E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
          STATION           CS             CBM             CTM
         78.500000       0.652587        0.237151        0.000000
        157.000000       1.081090        0.283293        0.015529
        235.500000       1.203835        0.191128        0.020297
        314.000000       1.208692        0.063794        0.018941
        392.500000       1.155750        0.065660        0.014713
        510.250000       0.939320        0.220889        0.000619
        605.959961       0.570484        0.244693        0.019877


CONTROL GAIN = 1.00
WAVE NUMBER =.20000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
        GY          GN          GL
    .61056E+00  .66184E+00  .29291E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
      SIDESLIP    YAW RATE    ROLL RATE     ROLL         YAW
    .19538E+01  .62877E-02  .98355E-03  .12233E+00  .80099E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
          STATION           CS             CBM             CTM
         78.500000       0.652520        0.237127        0.000000
        157.000000       1.080968        0.283263        0.015527
        235.500000       1.203700        0.191115        0.020295
        314.000000       1.208565        0.063822        0.018942
        392.500000       1.155663        0.065672        0.014724
        510.250000       0.939347        0.220851        0.001149
        605.959961       0.570771        0.244652        0.019909
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CONTROL GAIN = 1.00
WAVE NUMBER =.30000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
        GY            GN            GL
   .61046E+00    .66184E+00    .29287E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP      YAW RATE     ROLL RATE        ROLL           YAW
   .19535E+01    .94321E-02    .14764E-02    .12242E+00    .80103E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
        STATION             CS              CBM              CTM
        78.500000        0.652479         0.237113         0.000000
       157.000000        1.080882         0.283245         0.015526
       235.500000        1.203603         0.191114         0.020294
       314.000000        1.208486         0.063877         0.018947
       392.500000        1.155644         0.065697         0.014744
       510.250000        0.939501         0.220812         0.001696
       605.959961        0.571319         0.244610         0.019963


CONTROL GAIN = 1.00
WAVE NUMBER =.40000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
        GY            GN            GL
   .61036E+00    .66186E+00    .29282E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP      YAW RATE     ROLL RATE        ROLL           YAW
   .19531E+01    .12577E-01    .19705E-02    .12255E+00    .80110E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
        STATION             CS              CBM              CTM
        78.500000        0.652464         0.237108         0.000000
       157.000000        1.080831         0.283236         0.015524
       235.500000        1.203547         0.191126         0.020295
       314.000000        1.208454         0.063958         0.018955
       392.500000        1.155696         0.065737         0.014774
       510.250000        0.939781         0.220771         0.002247
       605.959961        0.572125         0.244566         0.020038
```

CONTROL GAIN = 1.00
WAVE NUMBER =.50000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61026E+00	.66189E+00	.29277E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19526E+01	.15723E-01	.24664E-02	.12271E+00	.80118E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.652472	0.237112	0.000000
157.000000	1.080811	0.283238	0.015523
235.500000	1.203527	0.191149	0.020296
314.000000	1.208468	0.064066	0.018966
392.500000	1.155814	0.065790	0.014814
510.250000	0.940183	0.220727	0.002800
605.959961	0.573187	0.244521	0.020135

CONTROL GAIN = 1.00
WAVE NUMBER =.60000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61015E+00	.66194E+00	.29272E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19521E+01	.18870E-01	.29645E-02	.12292E+00	.80129E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.652505	0.237125	0.000000
157.000000	1.080826	0.283250	0.015523
235.500000	1.203547	0.191184	0.020299
314.000000	1.208529	0.064199	0.018981
392.500000	1.156001	0.065856	0.014862
510.250000	0.940710	0.220682	0.003353
605.959961	0.574503	0.244474	0.020253

CONTROL GAIN = 1.00
WAVE NUMBER =.70000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61005E+00	.66201E+00	.29267E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19516E+01	.22019E-01	.34653E-02	.12316E+00	.80143E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.652563	0.237148	0.000000
157.000000	1.080874	0.283273	0.015523
235.500000	1.203606	0.191232	0.020303
314.000000	1.208636	0.064358	0.018999
392.500000	1.156256	0.065936	0.014919
510.250000	0.941358	0.220634	0.003906
605.959961	0.576067	0.244425	0.020392

CONTROL GAIN = 1.00
WAVE NUMBER =.80000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60994E+00	.66208E+00	.29261E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19509E+01	.25169E-01	.39692E-02	.12344E+00	.80158E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.652642	0.237178	0.000000
157.000000	1.080952	0.283304	0.015523
235.500000	1.203695	0.191289	0.020308
314.000000	1.208783	0.064541	0.019020
392.500000	1.156572	0.066030	0.014986
510.250000	0.942124	0.220583	0.004458
605.959961	0.577875	0.244374	0.020550

CONTROL GAIN = 1.00
WAVE NUMBER =.90000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60983E+00	.66218E+00	.29256E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19502E+01	.28322E-01	.44766E-02	.12376E+00	.80176E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.652746	0.237218	0.000000
157.000000	1.081063	0.283347	0.015523
235.500000	1.203826	0.191360	0.020314
314.000000	1.208977	0.064749	0.019044
392.500000	1.156957	0.066135	0.015061
510.250000	0.943009	0.220530	0.005010
605.959961	0.579925	0.244321	0.020728

CONTROL GAIN = 1.00
WAVE NUMBER =.10000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60972E+00	.66229E+00	.29251E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19495E+01	.31477E-01	.49879E-02	.12412E+00	.80196E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.652873	0.237266	0.000000
157.000000	1.081205	0.283398	0.015524
235.500000	1.203990	0.191441	0.020322
314.000000	1.209214	0.064982	0.019072
392.500000	1.157404	0.066254	0.015144
510.250000	0.944012	0.220475	0.005561
605.959961	0.582209	0.244267	0.020925

```
CONTROL GAIN = 1.00
WAVE NUMBER =.20000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
        GY           GN           GL
   .60855E+00   .66422E+00   .29195E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
   .19385E+01   .63203E-01   .10407E-01   .12961E+00   .80514E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
           STATION             CS             CBM             CTM
          78.500000         0.655331        0.238192        0.000000
         157.000000         1.084228        0.284409        0.015546
         235.500000         1.207438        0.192826        0.020448
         314.000000         1.213758        0.068485        0.019505
         392.500000         1.165116        0.068099        0.016393
         510.250000         0.959976        0.219805        0.011000
         605.959961         0.616645        0.243634        0.023769


CONTROL GAIN = 1.00
WAVE NUMBER =.30000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
        GY           GN           GL
   .60734E+00   .66763E+00   .29137E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
   .19219E+01   .95409E-01   .16626E-01   .13822E+00   .81028E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
           STATION             CS             CBM             CTM
          78.500000         0.659582        0.239786        0.000000
         157.000000         1.089580        0.286146        0.015588
         235.500000         1.213438        0.195057        0.020651
         314.000000         1.221411        0.073607        0.020178
         392.500000         1.177546        0.070917        0.018206
         510.250000         0.984723        0.218920        0.016262
         605.959961         0.666981        0.242840        0.027707
```

CONTROL GAIN = 1.00
WAVE NUMBER =.40000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60611E+00	.67249E+00	.29078E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19002E+01	.12828E+00	.23921E-01	.14936E+00	.81705E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.664992	0.241812	0.000000
157.000000	1.096274	0.288312	0.015634
235.500000	1.220762	0.197788	0.020895
314.000000	1.230692	0.079556	0.021009
392.500000	1.192676	0.074354	0.020329
510.250000	1.014871	0.217840	0.021289
605.959961	0.725697	0.241906	0.032163

CONTROL GAIN = 1.00
WAVE NUMBER =.50000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60491E+00	.67875E+00	.29020E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.18744E+01	.16192E+00	.32492E-01	.16253E+00	.82506E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.670868	0.244010	0.000001
157.000000	1.103226	0.290583	0.015668
235.500000	1.228059	0.200653	0.021144
314.000000	1.239993	0.085651	0.021921
392.500000	1.208345	0.078059	0.022575
510.250000	1.046979	0.216585	0.026046
605.959961	0.786528	0.240857	0.036769

```
CONTROL GAIN = 1.00
WAVE NUMBER =.60000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
         GY          GN          GL
     .60375E+00  .68635E+00  .28965E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
      SIDESLIP    YAW RATE    ROLL RATE     ROLL        YAW
     .18452E+01  .19637E+00  .42499E-01  .17739E+00  .83386E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
          STATION            CS           CBM           CTM
         78.500000        0.676571      0.246143      0.000001
        157.000000        1.109435      0.292660      0.015676
        235.500000        1.234082      0.203316      0.021365
        314.000000        1.247839      0.091398      0.022853
        392.500000        1.222612      0.081735      0.024827
        510.250000        1.078109      0.215178      0.030519
        605.959961        0.845046      0.239721      0.041318


CONTROL GAIN = 1.00
WAVE NUMBER =.70000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
         GY          GN          GL
     .60266E+00  .69521E+00  .28912E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
      SIDESLIP    YAW RATE    ROLL RATE     ROLL        YAW
     .18135E+01  .23162E+00  .54096E-01  .19378E+00  .84303E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
          STATION            CS           CBM           CTM
         78.500000        0.681585      0.248018      0.000002
        157.000000        1.114085      0.294300      0.015645
        235.500000        1.237824      0.205511      0.021536
        314.000000        1.253041      0.096473      0.023767
        392.500000        1.233947      0.085158      0.027024
        510.250000        1.106068      0.213641      0.034715
        605.959961        0.898493      0.238530      0.045700
```

CONTROL GAIN = 1.00
WAVE NUMBER =.80000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60166E+00	.70527E+00	.28864E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.17799E+01	.26757E+00	.67443E-01	.21164E+00	.85215E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.685551	0.249501	0.000003
157.000000	1.116611	0.295337	0.015570
235.500000	1.238585	0.207054	0.021647
314.000000	1.254781	0.100690	0.024645
392.500000	1.241320	0.088178	0.029145
510.250000	1.129460	0.211994	0.038656
605.959961	0.945418	0.237309	0.049866

CONTROL GAIN = 1.00
WAVE NUMBER =.90000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60075E+00	.71644E+00	.28821E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.17451E+01	.30410E+00	.82722E-01	.23099E+00	.86086E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.688266	0.250518	0.000004
157.000000	1.116686	0.295673	0.015445
235.500000	1.235962	0.207838	0.021697
314.000000	1.252598	0.103967	0.025490
392.500000	1.244175	0.090704	0.031196
510.250000	1.147586	0.210251	0.042378
605.959961	0.985304	0.236081	0.053804

```
CONTROL GAIN = 1.00
WAVE NUMBER =.10000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
        GY           GN           GL
   .59997E+00   .72864E+00   .28783E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
    SIDESLIP     YAW RATE     ROLL RATE       ROLL          YAW
   .17096E+01   .34102E+00   .10013E+00   .25189E+00   .86884E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
        STATION             CS             CBM            CTM
       78.500000         0.689658       0.251043       0.000005
      157.000000         1.114192       0.295275       0.015273
      235.500000         1.229813       0.207823       0.021693
      314.000000         1.246338       0.106289       0.026315
      392.500000         1.242351       0.092694       0.033197
      510.250000         1.160287       0.208427       0.045923
      605.999961         1.018267       0.234864       0.057526


CONTROL GAIN = 1.00
WAVE NUMBER =.20000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
        GY           GN           GL
   .60042E+00   .88883E+00   .28805E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
    SIDESLIP     YAW RATE     ROLL RATE       ROLL          YAW
   .13543E+01   .68749E+00   .43080E+00   .54589E+00   .87579E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
        STATION             CS             CBM            CTM
       78.500000         0.656477       0.238788       0.000041
      157.000000         0.988779       0.262610       0.012100
      235.500000         1.026686       0.174078       0.022943
      314.000000         1.027488       0.090419       0.038534
      392.500000         1.062360       0.090308       0.056385
      510.250000         1.123013       0.188221       0.080001
      605.999961         1.149684       0.223259       0.089738
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CONTROL GAIN = 1.00
WAVE NUMBER =.30000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61712E+00	.10700E+01	.29606E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.10015E+01	.88149E+00	.11321E+01	.95917E+00	.74861E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.609183	0.221343	0.000164
157.000000	0.807094	0.212946	0.010436
235.500000	0.750821	0.113441	0.033560
314.000000	0.815568	0.056161	0.061885
392.500000	1.018828	0.100347	0.090681
510.250000	1.332452	0.176517	0.123681
605.959961	1.502719	0.202710	0.129761

CONTROL GAIN = 1.00
WAVE NUMBER =.40000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.64448E+00	.12258E+01	.30919E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.62689E+00	.84652E+00	.23124E+01	.14714E+01	.53919E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.539106	0.194994	0.000445
157.000000	0.602973	0.150004	0.012275
235.500000	0.586367	0.058770	0.048647
314.000000	0.988963	0.120194	0.090035
392.500000	1.528344	0.181964	0.131892
510.250000	2.178324	0.191610	0.180129
605.959961	2.463434	0.155134	0.189809

CONTROL GAIN = 1.00
WAVE NUMBER =.50000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.67256E+00	.13310E+01	.32267E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.22627E+00	.59599E+00	.41715E+01	.21251E+01	.30369E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.364403	0.128290	0.001004
157.000000	0.364024	0.059589	0.015405
235.500000	0.822711	0.174830	0.063140
314.000000	1.663159	0.306992	0.118708
392.500000	2.583288	0.356857	0.177415
510.250000	3.687246	0.240926	0.252619
605.959961	4.143902	0.063612	0.280690

CONTROL GAIN = 1.00
WAVE NUMBER =.60000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.69215E+00	.13729E+01	.33206E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.32372E+00	.66510E+00	.72110E+01	.30628E+01	.28242E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.089675	0.034778	0.002084
157.000000	0.619974	0.206831	0.018375
235.500000	1.635498	0.479719	0.075633
314.000000	2.899204	0.677553	0.147766
392.500000	4.335018	0.708205	0.230148
510.250000	6.161600	0.347508	0.353578
605.959961	6.947445	0.147206	0.426636

CONTROL GAIN = 1.00
WAVE NUMBER =.70000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.65712E+00	.13477E+01	.33444E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.10359E+01	.20496E+01	.12865E+02	.46851E+01	.74601E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	1.078175	0.415664	0.004337
157.000000	2.011559	0.705097	0.021714
235.500000	3.432062	1.139404	0.088807
314.000000	5.265799	1.463589	0.183479
392.500000	7.539106	1.471949	0.303272
510.250000	10.656343	0.613297	0.518561
605.959961	12.141193	0.543728	0.694464

CONTROL GAIN = 1.00
WAVE NUMBER =.80000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.68519E+00	.12592E+01	.32872E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.21492E+01	.49919E+01	.22818E+02	.72727E+01	.15898E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	3.398520	1.288068	0.008790
157.000000	5.237886	1.808050	0.029149
235.500000	7.127623	2.503336	0.112733
314.000000	9.602432	3.034832	0.230361
392.500000	12.984966	3.014273	0.391142
510.250000	18.118134	1.230213	0.752460
605.959961	21.009048	1.346717	1.143815

CONTROL GAIN = 1.00
WAVE NUMBER =.90000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.65749E+00	.11188E+01	.31543E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.18131E+01	.49385E+01	.18925E+02	.53626E+01	.13980E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	3.942038	1.480221	0.008202
157.000000	5.791830	1.954727	0.032453
235.500000	6.972773	2.478195	0.106049
314.000000	8.352362	2.860790	0.182158
392.500000	10.387287	2.824291	0.258819
510.250000	14.054478	1.222084	0.498265
605.959961	16.787857	1.363981	0.883849

CONTROL GAIN = 1.00
WAVE NUMBER =.10000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61780E+00	.94575E+00	.29639E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.95681E+00	.30623E+01	.10617E+02	.27078E+01	.78021E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	2.764446	1.029070	0.005113
157.000000	4.115517	1.347707	0.032463
235.500000	4.671564	1.619162	0.085946
314.000000	5.085283	1.777737	0.138997
392.500000	5.630541	1.734595	0.162331
510.250000	7.039822	0.825724	0.216180
605.959961	8.828053	0.868258	0.456969

CONTROL GAIN = 1.00
WAVE NUMBER =.20000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.29319E+00	.88392E+00	.14066E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.15171E+00	.85362E+00	.21444E+01	.27357E+00	.10874E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	1.134851	0.428890	0.002065
157.000000	1.027805	0.417080	0.045517
235.500000	0.419911	0.334555	0.113475
314.000000	1.576807	0.669204	0.106022
392.500000	2.747778	0.669425	0.027104
510.250000	2.088320	0.384631	0.089759
605.559961	1.568931	0.345990	0.061418

CONTROL GAIN = 1.00
WAVE NUMBER =.30000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.10961E+00	.74178E+00	.52583E-02

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.69888E-01	.45828E+00	.11000E+01	.93563E-01	.38920E-01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.746151	0.289295	0.001589
157.000000	0.820849	0.106886	0.077070
235.500000	1.718292	0.512115	0.080923
314.000000	1.714957	0.575279	0.052645
392.500000	0.507745	0.587583	0.110879
510.250000	2.346483	0.154464	0.063739
605.559961	0.666339	0.220805	0.046188

CONTROL GAIN = 1.00
WAVE NUMBER =.40000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.24458E+00	.63639E+00	.11734E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.42791E-01	.29151E+00	.69200E+00	.44145E-01	.18567E-01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.577479	0.218872	0.001333
157.000000	1.283806	0.331974	0.075648
235.500000	1.408186	0.440649	0.058007
314.000000	1.231693	0.409548	0.084582
392.500000	1.844090	0.429579	0.074097
510.250000	2.016289	0.109567	0.049761
605.959961	0.334192	0.149185	0.026307

CONTROL GAIN = 1.00
WAVE NUMBER =.50000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.36215E+00	.52871E+00	.17374E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.28806E-01	.19294E+00	.45815E+00	.23381E-01	.98313E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.587817	0.207938	0.001103
157.000000	1.309130	0.424359	0.056520
235.500000	1.109384	0.128790	0.090783
314.000000	1.597287	0.391502	0.063433
392.500000	1.537951	0.346731	0.058937
510.250000	1.180824	0.242600	0.049153
605.959961	0.282871	0.089903	0.007541

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CONTROL GAIN = 1.00
WAVE NUMBER =.60000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
          GY           GN           GL
     .51347E+00   .45648E+00   .24634E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP     YAW RATE     ROLL RATE       ROLL          YAW
     .24027E-01   .13653E+00   .31816E+00   .13531E-01   .57977E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
             STATION                CS                CBM               CTM
           78.500000             0.643871          0.224073          0.000919
          157.000000             1.160705          0.337057          0.048572
          235.500000             1.548003          0.436300          0.079713
          314.000000             1.144318          0.294887          0.071796
          392.500000             1.014178          0.365458          0.068160
          510.250000             0.342652          0.314417          0.034207
          605.959961             0.559238          0.026384          0.035332


CONTROL GAIN = 1.00
WAVE NUMBER =.70000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
          GY           GN           GL
     .65821E+00   .39145E+00   .31577E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP     YAW RATE     ROLL RATE       ROLL          YAW
     .21951E-01   .96815E-01   .21346E+00   .77820E-02   .35238E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
             STATION                CS                CBM               CTM
           78.500000             0.672964          0.236792          0.000720
          157.000000             1.042583          0.221872          0.037322
          235.500000             1.341129          0.249397          0.079499
          314.000000             1.739594          0.330599          0.107653
          392.500000             1.996907          0.241195          0.116011
          510.250000             1.335586          0.276931          0.090908
          605.959961             0.910171          0.058437          0.083063
```

CONTROL GAIN = 1.00
WAVE NUMBER =.80000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.70105E+00	.40424E+00	.33632E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.20828E-01	.85142E-01	.17422E+00	.55582E-02	.27115E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.710651	0.255797	0.000671
157.000000	1.119725	0.286292	0.016938
235.500000	1.157343	0.230762	0.019276
314.000000	1.079087	0.271257	0.014323
392.500000	0.966950	0.333328	0.007527
510.250000	2.054621	0.174318	0.157054
605.959961	1.062377	0.109415	0.126236

CONTROL GAIN = 1.00
WAVE NUMBER =.90000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.83025E+00	.53478E+00	.39831E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.23639E-01	.99102E-01	.19222E+00	.54519E-02	.28055E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.768290	0.286460	0.000833
157.000000	1.374792	0.444364	0.028223
235.500000	1.736910	0.497258	0.073291
314.000000	1.772249	0.437751	0.107683
392.500000	1.406672	0.437562	0.119757
510.250000	2.502272	0.059268	0.097271
605.959961	1.277543	0.154797	0.094419

```
CONTROL GAIN = 1.00
WAVE NUMBER =.10000E+00

THE FORCING FUNCTION MAGNITUDES ARE:
        GY           GN           GL
    .12195E+01   .85551E+00   .58506E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
    .32686E-01   .14363E+00   .27620E+00   .70504E-02   .36595E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
          STATION          CS             CBM            CTM
         78.500000      0.807783       0.313902       0.001330
        157.000000      1.177675       0.391520       0.054205
        235.500000      0.619539       0.263421       0.100758
        314.000000      1.559916       0.635731       0.082192
        392.500000      2.848248       0.619200       0.054678
        510.250000      2.838743       0.231666       0.080567
        605.959961      2.083281       0.307855       0.114761
```

CONTROL GAIN = 2.00
WAVE NUMBER =.10000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61066E+00	.66185E+00	.29296E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19540E+01	.15719E-02	.48586E-03	.12230E+00	.40049E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.652624	0.237165	0.000000
157.000000	1.081154	0.283312	0.015531
235.500000	1.203919	0.191147	0.020300
314.000000	1.208793	0.063820	0.018947
392.500000	1.155873	0.065667	0.014725
510.250000	0.939482	0.220889	0.000940
605.959961	0.570731	0.244694	0.019890

CONTROL GAIN = 2.00
WAVE NUMBER =.20000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61056E+00	.66184E+00	.29291E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19538E+01	.31440E-02	.97271E-03	.12243E+00	.40051E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.652671	0.237183	0.000000
157.000000	1.081226	0.283337	0.015533
235.500000	1.204036	0.191191	0.020308
314.000000	1.208967	0.063927	0.018966
392.500000	1.156153	0.065702	0.014771
510.250000	0.940000	0.220854	0.001821
605.959961	0.571761	0.244655	0.019961

CONTROL GAIN = 2.00
WAVE NUMBER =.30000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61046E+00	.66184E+00	.29287E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19535E+01	.47165E-02	.14616E-02	.12265E+00	.40056E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.652818	0.237238	0.000000
157.000000	1.081465	0.283411	0.015537
235.500000	1.204360	0.191285	0.020324
314.000000	1.209392	0.064112	0.019001
392.500000	1.156748	0.065766	0.014851
510.250000	0.940967	0.220819	0.002713
605.959961	0.573540	0.244617	0.020080

CONTROL GAIN = 2.00
WAVE NUMBER =.40000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61036E+00	.66186E+00	.29282E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19531E+01	.62898E-02	.19536E-02	.12295E+00	.40063E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.653063	0.237330	0.000000
157.000000	1.081861	0.283531	0.015545
235.500000	1.204888	0.191427	0.020347
314.000000	1.210060	0.064374	0.019052
392.500000	1.157653	0.065859	0.014963
510.250000	0.942379	0.220783	0.003608
605.959961	0.576056	0.244579	0.020246

CONTROL GAIN = 2.00
WAVE NUMBER =.50000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61026E+00	.66189E+00	.29277E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19526E+01	.78639E-02	.24497E-02	.12335E+00	.40071E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.653406	0.237458	0.000000
157.000000	1.082419	0.283697	0.015555
235.500000	1.205618	0.191619	0.020378
314.000000	1.210970	0.064712	0.019117
392.500000	1.158864	0.065981	0.015107
510.250000	0.944231	0.220746	0.004504
605.959961	0.579298	0.244540	0.020458

CONTROL GAIN = 2.00
WAVE NUMBER =.60000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61015E+00	.66194E+00	.29272E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19521E+01	.94393E-02	.29509E-02	.12383E+00	.40082E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.653846	0.237622	0.000000
157.000000	1.083136	0.283909	0.015569
235.500000	1.206549	0.191859	0.020416
314.000000	1.212121	0.065124	0.019197
392.500000	1.160381	0.066131	0.015281
510.250000	0.946520	0.220708	0.005399
605.959961	0.583251	0.244501	0.020713

CONTROL GAIN = 2.00
WAVE NUMBER =.70000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.61005E+00	.66201E+00	.29267E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19515E+01	.11016E-01	.34582E-02	.12440E+00	.40095E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.654384	0.237822	0.000000
157.000000	1.084010	0.284167	0.015585
235.500000	1.207680	0.192147	0.020462
314.000000	1.213512	0.065610	0.019292
392.500000	1.162201	0.066310	0.015484
510.250000	0.949239	0.220669	0.006294
605.959961	0.587895	0.244461	0.021011

CONTROL GAIN = 2.00
WAVE NUMBER =.80000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60994E+00	.66208E+00	.29261E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19508E+01	.12594E-01	.39726E-02	.12505E+00	.40110E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.655014	0.238057	0.000000
157.000000	1.085037	0.284469	0.015604
235.500000	1.209004	0.192482	0.020515
314.000000	1.215137	0.066165	0.019401
392.500000	1.164316	0.066516	0.015715
510.250000	0.952381	0.220630	0.007187
605.959961	0.593210	0.244421	0.021349

CONTROL GAIN = 2.00
WAVE NUMBER =.90000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60983E+00	.66218E+00	.29256E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19501E+01	.14175E-01	.44950E-02	.12579E+00	.40127E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.655739	0.238326	0.000000
157.000000	1.086219	0.284817	0.015626
235.500000	1.210526	0.192865	0.020575
314.000000	1.216995	0.066789	0.019524
392.500000	1.166727	0.066750	0.015972
510.250000	0.955940	0.220589	0.008080
605.959961	0.599175	0.244380	0.021725

CONTROL GAIN = 2.00
WAVE NUMBER =.10000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60972E+00	.66229E+00	.29251E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19493E+01	.15757E-01	.50263E-02	.12660E+00	.40146E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.656558	0.238631	0.000000
157.000000	1.087554	0.285208	0.015650
235.500000	1.212238	0.193293	0.020642
314.000000	1.219084	0.067479	0.019660
392.500000	1.169428	0.067010	0.016255
510.250000	0.959908	0.220547	0.008971
605.959961	0.605764	0.244339	0.022138

CONTROL GAIN = 2.00
WAVE NUMBER =.20000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60855E+00	.66422E+00	.29195E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19379E+01	.31753E-01	.10997E-01	.13869E+00	.40450E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.669553	0.243458	0.000000
157.000000	1.108755	0.291394	0.016033
235.500000	1.239287	0.199927	0.021669
314.000000	1.251801	0.077395	0.021679
392.500000	1.211231	0.070974	0.020151
510.250000	1.019936	0.220081	0.017796
605.959961	0.700148	0.243899	0.027781

CONTROL GAIN = 2.00
WAVE NUMBER =.30000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60734E+00	.66763E+00	.29137E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19203E+01	.48214E-01	.18544E-01	.15613E+00	.40946E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.690015	0.251050	0.000000
157.000000	1.142145	0.301083	0.016631
235.500000	1.281615	0.210092	0.023219
314.000000	1.302605	0.090927	0.024569
392.500000	1.275225	0.076915	0.025169
510.250000	1.108882	0.219520	0.026386
605.959961	0.828241	0.243384	0.035007

CONTROL GAIN = 2.00
WAVE NUMBER =.40000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60611E+00	.67249E+00	.29078E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.18972E+01	.65337E-01	.27934E-01	.17660E+00	.41616E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.715768	0.260595	0.000001
157.000000	1.184151	0.313220	0.017375
235.500000	1.334583	0.222578	0.025099
314.000000	1.365805	0.105947	0.027921
392.500000	1.353838	0.084098	0.030568
510.250000	1.214911	0.218871	0.034655
605.959961	0.970067	0.242774	0.042784

CONTROL GAIN = 2.00
WAVE NUMBER =.50000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60491E+00	.67875E+00	.29020E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.18695E+01	.83280E-01	.39194E-01	.19840E+00	.42436E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.744517	0.271239	0.000001
157.000000	1.230999	0.326701	0.018198
235.500000	1.393380	0.236209	0.027136
314.000000	1.435636	0.121115	0.031440
392.500000	1.439771	0.091878	0.035979
510.250000	1.327999	0.218140	0.042540
605.959961	1.113428	0.242051	0.050612

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CONTROL GAIN = 2.00
WAVE NUMBER =.60000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
        GY            GN            GL
    .60375E+00    .68635E+00    .28965E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
      SIDESLIP      YAW RATE     ROLL RATE       ROLL          YAW
    .18379E+01    .10216E+00    .52227E-01    .22044E+00    .43378E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
         STATION             CS             CBM             CTM
        78.500000         0.774198        0.282217        0.000002
       157.000000         1.279286        0.340544        0.019040
       235.500000         1.453721        0.250004        0.029198
       314.000000         1.507099        0.135642        0.034937
       392.500000         1.527005        0.099770        0.041218
       510.250000         1.440807        0.217337        0.049998
       605.959961         1.251355        0.241201        0.058246


CONTROL GAIN = 2.00
WAVE NUMBER =.70000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
        GY            GN            GL
    .60266E+00    .69521E+00    .28912E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
      SIDESLIP      YAW RATE     ROLL RATE       ROLL          YAW
    .18034E+01    .12203E+00    .66899E-01    .24212E+00    .44416E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
         STATION             CS             CBM             CTM
        78.500000         0.803134        0.292908        0.000002
       157.000000         1.326241        0.353960        0.019853
       235.500000         1.512183        0.263224        0.031191
       314.000000         1.576289        0.149072        0.038298
       392.500000         1.611066        0.107432        0.046192
       510.250000         1.548426        0.216474        0.057008
       605.959961         1.379966        0.240219        0.065557
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CONTROL GAIN = 2.00
WAVE NUMBER =.80000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60166E+00	.70527E+00	.28864E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.17666E+01	.14293E+00	.83083E-01	.26317E+00	.45519E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.830094	0.302857	0.000003
157.000000	1.369819	0.366374	0.020603
235.500000	1.566272	0.275361	0.033057
314.000000	1.640429	0.161157	0.041463
392.500000	1.688923	0.114641	0.050858
510.250000	1.647837	0.215560	0.063568
605.959961	1.497267	0.239109	0.072482

CONTROL GAIN = 2.00
WAVE NUMBER =.90000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60075E+00	.71644E+00	.28821E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.17283E+01	.16483E+00	.10068E+00	.28354E+00	.46663E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.854249	0.311760	0.000004
157.000000	1.408638	0.377404	0.021270
235.500000	1.614327	0.286098	0.034762
314.000000	1.697717	0.171781	0.044402
392.500000	1.758718	0.121257	0.055205
510.250000	1.737387	0.214606	0.069692
605.959961	1.602442	0.237878	0.078997

CONTROL GAIN = 2.00
WAVE NUMBER =.10000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.59997E+00	.72864E+00	.28783E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.16891E+01	.18769E+00	.11966E+00	.30332E+00	.47820E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.875116	0.319439	0.000006
157.000000	1.441879	0.386826	0.021841
235.500000	1.655387	0.295262	0.036292
314.000000	1.747139	0.180914	0.047108
392.500000	1.819495	0.127205	0.059241
510.250000	1.816387	0.213616	0.075405
605.959961	1.695441	0.236541	0.085102

CONTROL GAIN = 2.00
WAVE NUMBER =.20000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60042E+00	.88883E+00	.28805E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.13045E+01	.44266E+00	.40969E+00	.51982E+00	.56390E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.914618	0.333503	0.000039
157.000000	1.481856	0.397810	0.022794
235.500000	1.702482	0.308223	0.044185
314.000000	1.842920	0.205594	0.065503
392.500000	1.995697	0.151700	0.088706
510.250000	2.139095	0.202347	0.117918
605.959961	2.129992	0.219566	0.129290

```
CONTROL GAIN = 2.00
WAVE NUMBER =.30000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
          GY             GN            GL
     .61712E+00   .10700E+01   .29606E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP     YAW RATE     ROLL RATE       ROLL          YAW
     .95592E+00   .64362E+00   .10244E+01   .86810E+00   .54660E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
            STATION            CS            CBM            CTM
           78.500000        0.804209       0.292035       0.000148
          157.000000        1.239575       0.328300       0.020030
          235.500000        1.398894       0.242813       0.048821
          314.000000        1.589475       0.169390       0.081069
          392.500000        1.851178       0.147635       0.114373
          510.250000        2.170668       0.192481       0.153343
          605.959961        2.274214       0.194651       0.162380


CONTROL GAIN = 2.00
WAVE NUMBER =.40000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
          GY             GN            GL
     .64448E+00   .12258E+01   .30919E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP     YAW RATE     ROLL RATE       ROLL          YAW
     .60835E+00   .67731E+00   .21449E+01   .13648E+01   .43141E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
            STATION            CS            CBM            CTM
           78.500000        0.663383       0.239121       0.000413
          157.000000        0.925644       0.234900       0.017891
          235.500000        1.050351       0.160683       0.056018
          314.000000        1.417698       0.159436       0.099714
          392.500000        1.922850       0.188756       0.144142
          510.250000        2.538595       0.198717       0.195497
          605.959961        2.777395       0.148928       0.205683
```

CONTROL GAIN = 2.00
WAVE NUMBER =.50000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.67258E+00	.13310E+01	.32267E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.23363E+00	.51131E+00	.40051E+01	.20403E+01	.26054E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.456905	0.161028	0.000964
157.000000	0.559799	0.116394	0.016971
235.500000	0.902206	0.168855	0.063951
314.000000	1.677668	0.289674	0.119623
392.500000	2.567989	0.338292	0.178215
510.250000	3.639133	0.237832	0.252218
605.959961	4.070953	0.061514	0.277598

CONTROL GAIN = 2.00
WAVE NUMBER =.60000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.69215E+00	.13729E+01	.33206E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.25511E+00	.60545E+00	.71795E+01	.30493E+01	.25709E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.037478	0.003586	0.002074
157.000000	0.454871	0.158499	0.016368
235.500000	1.427497	0.430645	0.070389
314.000000	2.658466	0.630644	0.139807
392.500000	4.057806	0.670002	0.219032
510.250000	5.843296	0.338461	0.337201
605.959961	6.617575	0.126528	0.405529

CONTROL GAIN = 2.00
WAVE NUMBER =.70000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.69712E+00	.13477E+01	.33444E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.94956E+00	.19692E+01	.13300E+02	.48435E+01	.71673E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.990999	0.386760	0.004483
157.000000	1.817941	0.660521	0.015726
235.500000	3.161425	1.082881	0.076846
314.000000	4.910086	1.400835	0.164414
392.500000	7.105391	1.420348	0.276938
510.250000	10.165751	0.604229	0.483844
605.959961	11.662699	0.517211	0.655407

CONTROL GAIN = 2.00
WAVE NUMBER =.80000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.68519E+00	.12592E+01	.32872E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19088E+01	.46280E+01	.22496E+02	.71696E+01	.14739E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	3.177864	1.206850	0.008666
157.000000	4.845032	1.685754	0.020133
235.500000	6.495617	2.303188	0.095681
314.000000	8.607546	2.768852	0.190768
392.500000	11.545469	2.755655	0.321689
510.250000	16.170898	1.148131	0.638637
605.959961	18.912399	1.234204	1.000337

```
CONTROL GAIN = 2.00
WAVE NUMBER =.90000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
        GY          GN          GL
     .65749E+00  .11188E+01  .31543E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
     .14224E+01  .40702E+01  .16442E+02  .46588E+01  .11522E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
           STATION              CS              CBM             CTM
           78.500000         3.307787        1.241728        0.007126
          157.000000         4.846958        1.633014        0.026030
          235.500000         5.746975        2.031952        0.093563
          314.000000         6.709463        2.308107        0.154535
          392.500000         8.129591        2.273863        0.201162
          510.250000        10.875336        1.008864        0.358588
          605.959961        13.144466        1.109520        0.667025


CONTROL GAIN = 2.00
WAVE NUMBER =.10000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
        GY          GN          GL
     .61780E+00  .94575E+00  .29639E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
     .77289E+00  .26211E+01  .95183E+01  .24275E+01  .66779E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
           STATION              CS              CBM             CTM
           78.500000         2.412622        0.897061        0.004584
          157.000000         3.597662        1.171357        0.028642
          235.500000         4.038742        1.381890        0.079553
          314.000000         4.298811        1.487326        0.130244
          392.500000         4.578722        1.443144        0.150225
          510.250000         5.499517        0.709948        0.159573
          605.959961         7.028250        0.730363        0.349401
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```
CONTROL GAIN = 2.00
WAVE NUMBER =.20000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
       GY           GN          GL
   .29319E+00   .88392E+00   .14066E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
   .14167E+00   .82556E+00   .21006E+01   .26798E+00   .10517E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
```

STATION	CS	CBM	CTM
78.500000	1.114007	0.420709	0.002023
157.000000	1.017117	0.407246	0.045883
235.500000	0.476656	0.310316	0.114601
314.000000	1.533462	0.636330	0.107860
392.500000	2.638281	0.636358	0.026232
510.250000	1.981400	0.373381	0.092132
605.959961	1.397262	0.331174	0.049663

```
CONTROL GAIN = 2.00
WAVE NUMBER =.30000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
       GY           GN          GL
   .10961E+00   .74178E+00   .52583E-02

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
     SIDESLIP     YAW RATE     ROLL RATE      ROLL          YAW
   .67613E-01   .45150E+00   .10901E+01   .92722E-01   .38345E-01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
```

STATION	CS	CBM	CTM
78.500000	0.743482	0.287993	0.001575
157.000000	0.830583	0.111672	0.077125
235.500000	1.703632	0.503706	0.080916
314.000000	1.698411	0.564004	0.052737
392.500000	0.532746	0.575804	0.112101
510.250000	2.301491	0.154395	0.062072
605.959961	0.606895	0.215734	0.042087

CONTROL GAIN = 2.00
WAVE NUMBER =.40000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.24458E+00	.63639E+00	.11734E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.42022E-01	.28907E+00	.68853E+00	.43923E-01	.18412E-01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.578510	0.219122	0.001326
157.000000	1.281893	0.330991	0.075632
235.500000	1.405575	0.437231	0.058027
314.000000	1.229513	0.404051	0.084807
392.500000	1.834221	0.423927	0.074144
510.250000	1.992366	0.111295	0.048653
605.959961	0.310158	0.146867	0.024347

CONTROL GAIN = 2.00
WAVE NUMBER =.50000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.36215E+00	.52871E+00	.17374E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.28506E-01	.19190E+00	.45669E+00	.23307E-01	.97785E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.588809	0.208348	0.001100
157.000000	1.306915	0.423239	0.056505
235.500000	1.111964	0.127333	0.090850
314.000000	1.595331	0.388788	0.063465
392.500000	1.530070	0.343851	0.058896
510.250000	1.170894	0.242278	0.049195
605.959961	0.282030	0.088861	0.006664

CONTROL GAIN = 2.00
WAVE NUMBER =.60000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.51347E+00	.45648E+00	.24634E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.23889E-01	.13602E+00	.31745E+00	.13501E-01	.57760E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.644243	0.224260	0.000917
157.000000	1.160934	0.336918	0.048574
235.500000	1.545453	0.435014	0.079663
314.000000	1.143443	0.293173	0.071804
392.500000	1.018844	0.363716	0.068332
510.250000	0.349154	0.313741	0.034506
605.959961	0.560294	0.025959	0.034816

CONTROL GAIN = 2.00
WAVE NUMBER =.70000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.65821E+00	.39145E+00	.31577E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.21878E-01	.96549E-01	.21309E+00	.77687E-02	.35141E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.673021	0.236835	0.000718
157.000000	1.043350	0.222257	0.037326
235.500000	1.341840	0.249165	0.079503
314.000000	1.738777	0.329683	0.107624
392.500000	1.994212	0.240145	0.115925
510.250000	1.336372	0.276469	0.090925
605.959961	0.910056	0.058689	0.082875

CONTROL GAIN = 2.00
WAVE NUMBER =.80000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.70105E+00	.40424E+00	.33632E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.20772E-01	.84963E-01	.17397E+00	.55504E-02	.27058E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.710547	0.255760	0.000670
157.000000	1.119617	0.286218	0.016938
235.500000	1.157223	0.230327	0.019290
314.000000	1.078794	0.270456	0.014362
392.500000	0.966160	0.332551	0.007610
510.250000	2.052601	0.174217	0.156994
605.959961	1.061211	0.109473	0.126129

CONTROL GAIN = 2.00
WAVE NUMBER =.90000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.83025E+00	.53478E+00	.39831E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.23581E-01	.98937E-01	.19200E+00	.54455E-02	.28008E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	CS	CBM	CTM
78.500000	0.768090	0.286371	0.000832
157.000000	1.374202	0.444054	0.028222
235.500000	1.735897	0.496672	0.073284
314.000000	1.771327	0.436963	0.107690
392.500000	1.406360	0.436707	0.119799
510.250000	2.498814	0.059653	0.097136
605.959961	1.274786	0.154661	0.094270

```
CONTROL GAIN = 2.00
WAVE NUMBER =.10000E+00

THE FORCING FUNCTION MAGNITUDES ARE:
           GY          GN          GL
      .12195E+01  .85951E+00  .58506E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
       SIDESLIP    YAW RATE    ROLL RATE      ROLL         YAW
      .32615E-01  .14344E+00  .27593E+00  .70436E-02  .36546E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
            STATION            CS             CBM            CTM
          78.500000         0.807538       0.313782       0.001329
         157.000000         1.177540       0.391286       0.054208
         235.500000         0.621107       0.262626       0.100790
         314.000000         1.558413       0.634651       0.082223
         392.500000         2.844856       0.618087       0.054568
         510.250000         2.834230       0.231392       0.080382
         605.959961         2.078382       0.307479       0.114399
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COMPUTER PROGRAM--NUMERICAL EXAMPLE

```
      REAL K,KC,KK,KS,IXX,IZZ,IXZ,LCG,LS,K1,K2
      COMPLEX YG,NG,LG,DYG,DNG,DLG,YGS,NGS,YGT,NGT,DYGT,E(23),GY,GN,GL,
     +C(5,5),D(5,5),B(5,5),R(5,1),WA(35),WK(5),DAE(7),DAIE(7),
     +DSHR(7),DBEND(7),DTWIST(7),SHEAR(7),BEND(7),TWIST(7),SEARS
      DIMENSION RMAG(5),RPHASE(5),X(23),Y(23),A(23),DIXZ(8),DHCG(8),
     +XENG(8),ZENG(8),DA(7),DAX(7),DAX2(7),NDIV(9),DM(8),DIXX(8),
     +CSSMAG(7),CBMMAG(7),CTMMAG(7),DIZZ(8)
      DATA KK/.93225/,ETA/.2600/,SS/16868./,LS/665.84/,
     +STK/209.44/,CLAS/1.8310/,CYBT/.14/,S/37914./,CBAR/785./,CS/100./,
     +PI/3.141593/,G/32.174/,K1/.0440/,K2/.9140/
      KC=2.0
      RHO=.002308
      UO=123.
      Q=.5*RHO*UO**2
      BUOY=548642.
      HCG=-37.66
      LCG=364.24
      ALPHA=.0037
      COSA=COS(ALPHA)
      TANA=TAN(ALPHA)
      SECA=1./COSA
      XB=363.01
      ZB=(-HCG+(LCG-XB)*TANA)*COSA
C
C     READ IN AIRSHIP GEOMETRY
C
      READ (5,800)(X(I),I=1,23)
      READ (5,800) (Y(I),I=1,23)
      READ(5,800)(XENG(I),I=1,8)
      READ(5,800)(ZENG(I),I=1,8)
  800 FORMAT(F15.5)
      DO 1 I=1,8
      READ (5,810) DM(I),DIXX(I),DIZZ(I),DIXZ(I),DHCG(I)
  810 FORMAT(5(F10.6))
    1 CONTINUE
      READ(5,800) OMEGA
      IF(OMEGA.LT.0.) GO TO 50
C
C     CALCULATE FORCING FUNCTIONS
C
      DO 5 I=1,23
      A(I)=PI*Y(I)**2
      E(I)=CEXP(CMPLX(0.,-OMEGA*X(I)*COSA))
    5 CONTINUE
      K=OMEGA*CBAR/2.
      KS=OMEGA*CS/2.
      YG=CEXP(CMPLX(0.,-OMEGA*X(17)*COSA))*A(17)
      NG=YG*X(17)
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      DYG=(0.,0.)                                                        THE00490
      DNG=(0.,0.)                                                        THE00500
      DO 10 I=1,17                                                       THE00510
      DYG=DYG+(E(I+1)*A(I+1)+E(I)*A(I))/2.*(X(I+1)-X(I))                 THE00520
      DNG=DNG+((E(I+1)-CMPLX(0.,OMEGA)*CCSA*X(I+1)*E(I+1))*A(I+1)        THE00530
     $+(E(I)-CMPLX(0.,OMEGA)*COSA*X(I)*E(I))*A(I))/2.*(X(I+1)-X(I))      THE00540
10    CONTINUE                                                           THE00550
      YG=2.*(YG+DYG*CMPLX(0.,OMEGA)*CCSA)*KK                             THE00560
      NG=2.*(NG+DNG)                                                     THE00570
      CALL SEARFN(KS,SEARS)                                              THE00580
      YGS=SS*CLAS*SEARS*ETA*CEXP(CMPLX(0.,-OMEGA*LS*COSA))               THE00590
      NGS=YGS*LS                                                         THE00600
      NGT=(0.,0.)                                                        THE00610
      YGT=(0.,0.)                                                        THE00620
      DO 20 I=1,8                                                        THE00630
      DYGT=STK*CYBT*CEXP(CMPLX(0.,-OMEGA*XENG(I)*COSA))                  THE00640
      YGT=YGT+DYGT                                                       THE00650
      NGT=NGT+DYGT*XENG(I)                                               THE00660
20    CONTINUE                                                           THE00670
      YG=YG+YGS+YGT                                                      THE00680
      NG=NG+NGS+NGT-LCG*YG                                               THE00690
      LG=-HCG*YG                                                         THE00700
      CY=YG/S                                                            THE00710
      CN=NG/S/CBAR                                                       THE00720
      CL=LG/S/CBAR                                                       THE00730
C                                                                        THE00740
C    BEGIN DYNAMICS CALCULATIONS                                         THE00750
C                                                                        THE00760
      MASS=17038.6                                                       THE00770
      IXX=38585100.                                                      THE00780
      IZZ=471799000.                                                     THE00790
      IXZ=102129000.                                                     THE00800
      DO 25 I=1,5                                                        THE00810
      DO 22 J=1,5                                                        THE00820
      C(I,J)=(0.,0.)                                                     THE00830
      D(I,J)=(0.,0.)                                                     THE00840
22    CONTINUE                                                           THE00850
25    CONTINUE                                                           THE00860
      C(1,1)=(-.7224,0.)                                                 THE00870
      C(1,3)=(-.0648,0.)                                                 THE00880
      C(1,2)=CMPLX(-.3418-4.*MASS/(RHO*S*CBAR),0.)                       THE00890
      C(1,5)=CMPLX(-KC,0.)                                               THE00900
      C(2,1)=(-.1710,0.)                                                 THE00910
      C(2,3)=(-.0150,0.)                                                 THE00920
      C(2,2)=(-.2352,0.)                                                 THE00930
      C(2,4)=CMPLX(-XB/CBAR*BUOY/(Q*S),0.)*CCSA                          THE00940
      C(2,5)=CMPLX((.350624*KC),0.)                                      THE00950
      C(3,1)=(-.0322,0.)                                                 THE00960
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      C(3,3)=(-.0066,0.)                                                THE00970
      C(3,2)=(-.0153,0.)                                                THE00980
      C(3,4)=CMPLX(-ZB/CBAR*BUOY/(Q*S),0.)                              THE00990
      C(3,5)=CMPLX((-.048051*KC),0.)                                    THE01000
      C(4,3)=(1.,0.0)                                                   THE01010
      C(4,2)=CMPLX(TANA,0.)                                             THE01020
      C(5,2)=CMPLX(SECA,0.)                                             THE01030
      D(1,1)=CMPLX(0.,2.*MASS/(RHO*S*CBAR)+.9863)                       THE01040
      D(1,3)=(0.,.0913)                                                 THE01050
      D(1,2)=(0.,-.0586)                                                THE01060
      D(2,1)=(0.,-.0293)                                                THE01070
      D(2,3)=CMPLX(0.,-8.*IXZ/(RHO*S*CBAR**3)-.0028)                    THE01080
      D(2,2)=CMPLX(0.,8.*IZZ/(RHO*S*CBAR**3)+.0991)                     THE01090
      D(3,1)=(0.,.0456)                                                 THE01100
      D(3,3)=CMPLX(0.,IXX*8./(RHO*S*CBAR**3)+.0042)                     THE01110
      D(3,2)=CMPLX(0.,-IXZ*8./(RHO*S*CBAR**3)-.0028)                    THE01120
      D(4,4)=(0.,1.)                                                    THE01130
      D(5,5)=(0.,1.)                                                    THE01140
      DO 40 I=1,5                                                       THE01150
      DO 30 J=1,5                                                       THE01160
      B(I,J)=C(I,J)-K*D(I,J)                                            THE01170
30    CONTINUE                                                          THE01180
40    CONTINUE                                                          THE01190
      R(1,1)=GY                                                         THE01200
      R(2,1)=GN                                                         THE01210
      R(3,1)=GL                                                         THE01220
      R(4,1)=(0.,0.)                                                    THE01230
      R(5,1)=(0.,0.)                                                    THE01240
      IJOB=0                                                            THE01250
      IER=0                                                             THE01260
      N=5                                                               THE01270
      M=1                                                               THE01280
      CALL LEQ2C(B,N,N,R,M,N,IJOB,WA,WK,IER)                            THE01290
      GYMAG=CABS(GY)                                                    THE01300
      GNMAG=CABS(GN)                                                    THE01310
      GLMAG=CABS(GL)                                                    THE01320
      DO 45 I=1,5                                                       THE01330
      RMAG(I)=CABS(R(I,1))                                              THE01340
45    CONTINUE                                                          THE01350
      WRITE (6,700) KC                                                  THE01360
700   FORMAT (///,' CONTROL GAIN = ',F4.2)                              THE01370
      WRITE (6,901)OMEGA                                                THE01380
901   FORMAT(/,' WAVE NUMBER ='E10.5)                                   THE01390
      WRITE (6,900)                                                     THE01400
900   FORMAT(//' THE FORCING FUNDTION MAGNITUDES ARE:'//                THE01410
     $,11X,'GY',10X,'GN',10X,'GL')                                      THE01420
      WRITE(6,910)GYMAG,GNMAG,GLMAG                                     THE01430
910   FORMAT(5X,3(2X,E10.5))                                            THE01440
```

```
      WRITE(6,905)
905   FORMAT(//,' THE MOTICN RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:'
     $,//,8X,'SIDESLIP',4X,'YAW RATE',4X,'ROLL RATE',5X,'ROLL',9X,'YAW')
      WRITE (6,915) (RMAG(I),I=1,5)
915   FORMAT(5X,5(2X,E10.5))
C
C   CALCULATE THE LOADING TRANSFER FUNCTICNS
C
      NDIV(1)=1
      NDIV(2)=4
      NDIV(3)=6
      NDIV(4)=8
      NDIV(5)=10
      NDIV(6)=12
      NDIV(7)=15
      NDIV(8)=18
      NDIV(9)=23
      DO 80 I=1,7
      DA(I)=0.
      DAE(I)=(0.,0.)
      DAIE(I)=(0.,0.)
      DAX(I)=0.
      DAX2(I)=0.
      J1=NDIV(I)
      J2=NDIV(I+1)-1
      DO 70 J=J1,J2
      DK=(X(J+1)-X(J))
      DAE(I)=DAE(I)+(A(J+1)*E(J+1)+A(J)*E(J))/2.*DX
      DA(I)=DA(I)+(A(J+1)+A(J))/2.*DX
      DAX(I)=DAX(I)+(A(J+1)*X(J+1)+A(J)*X(J))/2.*DX
      DAIE(I)=DAIE(I)+(A(J+1)*X(J+1)*E(J+1)+A(J)*X(J)*E(J))/2.*DX
      DAX2(I)=DAX2(I)+(X(J+1)**2*A(J+1)+X(J)**2*A(J))/2.*DX
70    CONTINUE
C
C   SHEAR CALCULATIONS
C
      DSHR(I)=(A(NDIV(I+1))*E(NDIV(I+1))-A(NDIV(I))*E(NDIV(I))+(0.,1.)*
     $OMEGA*COSA*DAE(I))*2.*C*KK
      DSHR(I)=DSHR(I)+2.*Q*KK*R(1,1)*(A(NDIV(I+1))-A(NDIV(I)))
      DSHR(I)=DSHR(I)-Q*KK*4./CBAR*R(2,1)*(A(NDIV(I+1))*(LCG-
     $X(NDIV(I+1)))-A(NDIV(I))*(LCG-X(NDIV(I)))-DA(I))
      DSHR(I)=DSHR(I)+2.*Q*(0.,1.)*OMEGA*R(1,1)*DA(I)*K2
      DSHR(I)=DSHR(I)-C*4./CBAR*K2*(0.,1.)*OMEGA*(LCG*(DA(I)
     $-DAX(I))*R(2,1))
      DSHR(I)=DSHR(I)+C*4./CBAR*R(2,1)*K1*DA(I)
      DSHR(I)=DSHR(I)+COSA*RHO*G*DA(I)*R(4,1)
      DSHR(I)=DSHR(I)+(-U0**2*(0.,1.)*OMEGA*R(1,1)-2./CBAR*(0.,1.)
     $*OMEGA*R(2,1)*(LCG-(X(NDIV(I))+X(NDIV(I+1)))/2.)-2.*U0**2/CBAR
```

```
     $*R(2,1)-G*COSA*R(4,1))*DM(I)
C
C    BENDING CALCULATIONS
C
      DBEND(I)=LCG*DSHR(I)
      DBEND(I)=DBEND(I)-(X(NDIV(I+1))*A(NDIV(I+1))*E(NDIV(I+1))-X(NDIV(I
     $))*A(NDIV(I))*E(NDIV(I))-DAE(I)+DAIE(I))*2.*Q*KK
      DBEND(I)=DBEND(I)-2.*C*KK*R(1,1)*(X(NDIV(I+1))*A(NDIV(I+1))-
     $X(NDIV(I))*A(NDIV(I))-DA(I))
      DBEND(I)=DBEND(I)+4./CBAR*Q*KK*R(2,1)*(LCG*(X(NDIV(I+1))
     $*A(NDIV(I+1))-X(NDIV(I))*A(NDIV(I)))-X(NDIV(I+1))**2*A(NDIV(I+1))
     $+X(NDIV(I))**2*A(NDIV(I))+2.*DAX(I))
      DBEND(I)=DBEND(I)-2.*Q*(0.,1.)*OMEGA*R(1,1)*DAX(I)*K2
      DBEND(I)=DBEND(I)+C*(0.,1.)*OMEGA*4./CBAR*R(2,1)*K2*(LCG*DAX(I)
     $-DAX2(I))
      DBEND(I)=DBEND(I)-4./CBAR*Q*R(2,1)*K1*DAX(I)
      DBEND(I)=DBEND(I)-COSA*R(4,1)*RHO*G*DAX(I)
      DBEND(I)=DBEND(I)+UO**2*(0.,1.)*OMEGA*R(1,1)*(X(NDIV(I+1))
     $+X(NDIV(I)))/2.*DM(I)
      DBEND(I)=DBEND(I)+2./CBAR*UO**2*(0.,1.)*OMEGA*R(2,1)*((LCG
     $*X(NDIV(I+1))-X(NDIV(I+1))**2)+(LCG*X(NDIV(I))-X(NDIV(I))**2))
     $/2.*DM(I)
      DBEND(I)=DBEND(I)+G*COSA*R(4,1)*(X(NDIV(I+1))+X(NDIV(I)))/2.*DM(I)
      DBEND(I)=DBEND(I)+2./CBAR*UO**2*R(2,1)*(X(NDIV(I+1))+X(NDIV(I)))
     $/2.*DM(I)
      DBEND(I)=DBEND(I)+(0.,1.)*OMEGA*2./CBAR*(DIXZ(I)*R(3,1)-DIZZ(I)
     $*R(2,1))
C
C    TWISTING CALCULATIONS
C
      DTWIST(I)=(-DHCG(I))*DSHR(I)+(0.,1.)*OMEGA*2./CBAR*UO**2*(DIXZ(I)
     $*R(2,1)-DIXX(I)*R(3,1))+DHCG(I)*G*DM(I)*COSA*R(4,1)
80    CONTINUE
      DO 110 L=1,7
      SHEAR(L)=(0.,0.)
      BEND(L)=(0.,0.)
      TWIST(L)=(0.,0.)
      DO 90 I=1,L
      SHEAR(L)=SHEAR(L)+DSHR(I)
      BEND(L)=BEND(L)+DBEND(I)
      TWIST(L)=TWIST(L)+DTWIST(I)
90    CONTINUE
      DO 100 J=1,6
      IF(XENG(J).GE.X(NDIV(L+1))) GO TO 100
      YT=Q*STK*CYBT*(CEXP(CMPLX(0.,-OMEGA*XENG(J)*COSA))*R(1,1)
     $-2./CBAR*R(2,1)*(LCG-XENG(J))-2./CBAR*R(3,1)*(HCG-ZENG(J)))
      SHEAR(L)=SHEAR(L)-YT
      BEND(L)=BEND(L)+(X(NDIV(L+1))-XENG(J))*YT
```

```
      TWIST(I)=TWIST(L)-ZENG(J)*YT
100   CONTINUE
      CSSMAG(L)=CABS(SHEAR(L)*2./(Q*S))
      CBMMAG(L)=CABS(BEND(L)*2./(Q*S*CBAR))
      CTMMAG(L)=CABS(TWIST(L)*2./(Q*S*CBAR))
110   CONTINUE
      WRITE(6,950)
950   FORMAT(//,' THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
     $',//,12X,'STATION',11X,'CS',12X,'CBM',13X,'CTM')
      DO 120 I=1,7
      WRITE(6,960) X(NDIV(I+1)),CSSMAG(I),CBMMAG(I),CTMMAG(I)
960   FORMAT(5X,4(5X,F10.6))
120   CONTINUE
      GO TO 1
50    CONTINUE
      STOP
      END
      SUBROUTINE SEARFN (RFFIN,SEARS)
C
C    THIS SUBRUOTINE CALCULATES THE SEARS FUNCTION CORRECTED FOR
C    ASPECT RATIO
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMPLEX*16 SEARSC,EMUK,GKAR,GAMHAT,FILOFN
      COMPLEX*16 DCMPLX
      COMPLEX SEARS
      IF (RFFIN) 72,72,73
72    SEARS=CCMPLX(1.0D0,0.0D0)
      GO TO 71
73    RF1=RFFIN/3.0
      BESSJ0=1.0-2.250*(RF1**2)+1.26562*(RF1**4)-.31639*(RF1**6)
     $+.04445*(RF1**8)-.00394*(RF1**10)
      BESSJ1=RFFIN*(.50-.56250*(RF1**2)+.21094*(RF1**4)-.03945*(RF1**6)
     $+.00443*(RF1**8))
      BESSY0=.63662*DLOG(.5*RFFIN)*BESSJ0+.36747+.60559*(RF1**2)
     $-.74350*(RF1**4)+.25300*(RF1**6)-.04261*(RF1**8)
      BESSY1=.63662*DLOG(.5*RFFIN)*BESSJ1-(1.0/RFFIN)*(.63662
     $-.22121*(RF1**2)-2.16827*(RF1**4)+1.31648*(RF1**6)
     $-.31240*(RF1**8))
      AR=1.87
      RF2=RFFIN*AR/3.75
      BESSI1=RFFIN*AR*(.50+.87891*(RF2**2)+.51499*(RF2**4)
     $+.15085*(RF2**6)+.02659*(RF2**8))
      RF3=RFFIN*AR/2.0
      BESSK1=DLOG(RF3)*BESSI1+(1.0/(RFFIN*AR))*(1.0+.15443*(RF3**2)
     $-.67279*(RF3**$4)-.18157*(RF3**6)-.01919*(RF3**8)
     $-.00110*(RF3**10))
      RF4=RFFIN*AR
```

```
      STRUL1=.63662*(.33333*(RF4**2)+.02222*(RF4**4)                     THE02890
     $+.000635*(RF4**6)+.000010078*(RF4**8)+.0000001018*(RF4**10)        THE02900
     $+.00000000071188*(RF4**12))                                        THE02910
      SEARS0=2.0/(3.14159*RFFIN*DCMPLX(BESSJ0-BESSY1,-BESSJ1-BESSY0))    THE02920
      EMUK=.5*SEARS0*DCMPLX(BESSJ0,-BESSJ1)                              THE02930
      GKAR=DCMPLX(BESSK1,-(1.0-1.57080*(STRUL1-BESSI1)))                 THE02940
      GAMHAT=1.0/(1.0+4.0*RFFIN*EMUK*GKAR)                               THE02950
      SEARS=SEARS0*GAMHAT                                                THE02960
   71 RETURN                                                             THE02970
      END                                                                THE02980
```

```
      REAL*8 EPS,XL,XR,XAPP,F
      REAL*4 I3(8),MQ(8),MQDCT(8),LKEEL(8),MFRAME(8),LK,
     $IXZTOT,IXZFIN,IXXFIN,IYYFIN,IZZFIN,IXXTOT,IYYTOT,IZZTOT,
     $IXX(8),IYY(8),IZZ(8),IXZ(8),IXXF(8),IYYF(8),IZZF(8)
      DIMENSION SIXXE(8),SIYYE(8),SIZZE(8),X(100),Y(100),NDIV(9),
     $VCENTR(8),ASLRF(8),APRCJ(8),XBARH(8),ZBARH(8),XBARA(8),ZBARA(8),
     $VHEL(8),VAIR(8),CAPRCJ(8),XBARF(8),XKEEL(8),WK(8),XK(8),XENG(5),
     $YENG(5),ZENG(5),XE(5,8),YE(5,8),ZE(5,8),WE(5,8),XCG(8),YCG(8),
     $ZCG(8),CWTOT(8),BUOY(8),VOL(8),DHEL(100),DAIR(100),HHEL(100),
     $HAIR(100)
      COMMON/AIR/X,Y,VOLAIR,N
      EXTERNAL F
      M=8
      N=23
      READ (5,900) (X(I),I=1,N)
      READ (5,900) (Y(I),I=1,N)
900   FORMAT(F10.3)
      PI=3.1415927
C
C     THE HULL IS DIVIDED INTO M SEGMENTS...THE BOUNDRIES OF EACH
C     ARE DEFINED AS NDIV(I)
C
      NDIV(1)=1
      NDIV(2)=4
      NDIV(3)=6
      NDIV(4)=8
      NDIV(5)=10
      NDIV(6)=12
      NDIV(7)=15
      NDIV(8)=18
      NDIV(9)=N
C
C     FOR THE AERODYNAMIC MODEL IT IS NECESSARY TO FIND THE FOLLOWING
C     GEOMETRIC PARAMETERS FOR EACH OF THE M HULL SECTIONS...
C     VOLUME, PROJECTED AREA, SURFACE AREA, CENTER OF PROJECTED
C     AREA, I3, MQDCT, AND MQ
C
      DO 10 J=1,M
      SUM1=0.
      SUM2=0.
      SUM3=0.
      SUM4=0.
      K1=NDIV(J)
      K2=NDIV(J+1)-1
      DO 20 I=K1,K2
      DELTAX=X(I+1)-X(I)
      SUM1=SUM1+PI/2.*(Y(I)**2+Y(I+1)**2)*DELTAX
      SUM2=SUM2+(Y(I)+Y(I+1))*DELTAX
```

```
      SUM3=SUM3+PI*DELTAX*(X(I)*Y(I)**2+X(I+1)*Y(I+1)**2)/2.
      SUM4=SUM4+(X(I)*Y(I)+X(I+1)*Y(I+1))*DELTAX
C
C     THE NEXT 4 VARIABLES ARE USED LATER IN THE INERTIA CALCULATIONS
C
      HAIR(I)=0.
      DAIR(I)=0.
      CHEL(I)=PI/2.*(Y(I)**2+Y(I+1)**2)*DELTAX
      HHEL(I)=0.
20    CONTINUE
      VOL(J)=SUM1
      APROJ(J)=SUM2
      ASURF(J)=PI*SUM2
      VCENTR(J)=SUM3/VOL(J)
      CAPROJ(J)=SUM4/APROJ(J)
10    CONTINUE
      DO 30 J=1,M
      SUM5=0.
      SUM6=0.
      SUM7=0.
      K1=NDIV(J)
      K2=NDIV(J+1)-1
      DO 40 I=K1,K2
      DELTAX=X(I+1)-X(I)
      DELTAA=PI*(Y(I+1)**2-Y(I)**2)
      DX1=X(I)-VCENTR(J)
      DX2=X(I+1)-VCENTR(J)
      SUM5=SUM5+(DX1+DX2)/2.*DELTAA
      SUM6=SUM6+PI*DELTAX*(DX1**2*Y(I)**2+DX2**2*Y(I+1)**2)/2.
      SUM7=SUM7+(DX1**2+DX2**2)/2.*DELTAA
40    CONTINUE
      I3(J)=SUM5
      MQDOT(J)=SUM6
      MQ(J)=SUM7
30    CONTINUE
      WRITE (6,201)
      WRITE(6,202) (VOL(I),I=1,M)
      WRITE(6,203) (ASURF(I),I=1,M)
      WRITE (6,204) (APROJ(I),I=1,M)
      WRITE (6,205) (VCENTR(I),I=1,M)
      WRITE(6,206) (CAPROJ(I),I=1,M)
      WRITE(6,207) (I3(I),I=1,M)
      WRITE(6,208) (MQDOT(I),I=1,M)
      WRITE(6,209) (MQ(I),I=1,M)
201   FORMAT(////,57X,'AKRON     ',//,2X,'SEGMENT NUMBER',6X,'1',12X,
     +'2',12X,'3',12X,'4',12X,'5',12X,'6',12X,'7',12X,'8')
202   FORMAT(//,2X,'VOLUME',8X,8(1X,E12.6))
203   FORMAT(//,2X,'SURFACE AREA',2X,8(1X,E12.6))
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204   FORMAT(//,2X,'PRCJECTED AREA',8(1X,E12.6))                            AKR00970
205   FORMAT(//,2X,'CENTER CF VOL',1X,8(1X,E12.6))                          AKR00980
206   FORMAT(//,2X,'CENTER CF PA',2X,8(1X,E12.6))                           AKRC0990
207   FORMAT(//,2X,'I3',12X,8(1X,E12.5))                                    AKR01000
208   FORMAT(//,2X,'-MCDCT/K3/RHO',1X,8(1X,E12.6))                          AKR01010
209   FORMAT(//,2X,'-MC/2/Q/K*U',3X,8(1X,E12.5))                            AKR01020
      VOLUME=0.                                                             AKR01030
      SURFAC=0.                                                             AKRC1040
      DO 50 J=1,M                                                           AKR01050
      VOLUME=VCLUME+VCL(J)                                                  AKR01060
      SURFAC=SURFAC+ASURF(J)                                                AKRC1070
50    CONTINUE                                                              AKR01080
C                                                                           AKR01090
C     THE SHEAR AND BENDING MCMENTS DEPEND CN THE MASSES AND MOMENTS OF     AKR01100
C     INERTIA FCR EACH SEGMENT.  THE TOTAL WEIGHT OF THE AIRSHIP MUST BE    AKR01110
C     KNCWN.                                                                AKRC1120
C     W=WEIGHT OF FRAME+ENGINES+FINS+KEEL+HELIUM+AIR    (LBS)               AKR01130
C                                                                           AKR01140
      WFRAME=259823.*.0153114*32.2                                          AKR01150
      WENGS=118.82*32.2*4.                                                  AKR01160
      WFINS=121.118*32.2                                                    AKR01170
      WKEEL=8152.2*32.2                                                     AKR01180
      WTOT=WFRAME+WENGS+WFINS+WKEEL                                         AKR01190
      XFINS=667.49                                                          AKR01200
C                                                                           AKR01210
C     CAN NOW SOLVE FOR THE VCLUMES OF AIR AND HELIUM IN EACH SEGMENT.      AKR01220
C                                                                           AKR01230
      RHOAIR=.002308                                                        AKR01240
      RHOHEL=.000358449                                                     AKR01250
      VOLAIR=VOLUME-WTOT/32.2/(RHOAIR-RHOHEL)                               AKR01260
      VOLHEL=VOLUME-VOLAIR                                                  AKR01270
      WRITE(6,210) VOLHEL,VOLAIR,VOLUME                                     AKR01280
210   FORMAT(//,10X,'HELIUM VOLUME = ',E14.6,//,10X,'AIR VOLUME = ',        AKR01290
     +E14.6,//,10X,'TOTAL VOLUME = ',E14.6,//)                              AKR01300
C                                                                           AKR01310
C     NOW MUST ITTERATE TO FIND A DISTANCE D SUCH THAT THE VOLUME OF AIR    AKR01320
C     BELOW IT EQUALS 'VOLAIR'.                                             AKR01330
C                                                                           AKRC1340
      EPS=1.                                                                AKRC1350
      NSIG=5                                                                AKR01360
      XL=30.                                                                AKR01370
      XR=45.                                                                AKRC1380
      ITMAX=100                                                             AKR01390
      CALL ZFALSE(F,EPS,NSIG,XL,XR,XAPP,ITMAX,IER)                          AKR01400
      D=XAPP                                                                AKRC1410
C                                                                           AKR01420
C     NOW KNOWING D, IT IS POSSIBLE TO CALCULATE THE QUANTITY OF AIR IN A   AKR01430
C     SEGMENT.                                                              AKR01440
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C     VAIR(I)=VOLUME OF AIR IN THE I'TH SEGMENT                          AKR01450
C     XBARA(I)=DISTANCE FROM NOSE FO CG OF AIR IN THE I'TH SEGMENT       AKR01460
C     ZBARA(I)=DISTANCE FROM CENTER LINE TO AIR CG                       AKR01470
C     SIMILAR CONVENTION FOR HELIUM                                      AKR01480
C                                                                        AKR01490
      DO 100 J=1,M                                                       AKR01500
      SUM9=0.                                                            AKR01510
      SUM10=0.                                                           AKR01520
      SUM11=0.                                                           AKR01530
      K1=NDIV(J)                                                         AKR01540
      K2=NDIV(J+1)-1                                                     AKR01550
      DO 110 I=K1,K2                                                     AKR01560
      IF (Y(I).LT.D)GO TO 110                                            AKR01570
      IF(Y(I+1).LT.D)GO TO 110                                           AKR01580
      ALPHA1=ARCOS(D/Y(I))                                               AKR01590
      ALPHA2=ARCOS(D/Y(I+1))                                             AKR01600
      A1=Y(I)**2/2.*(2.*ALPHA1-SIN(2.*ALPHA1))                           AKR01610
      A2=Y(I+1)**2/2.*(2.*ALPHA2-SIN(2.*ALPHA2))                         AKR01620
      DELTAX=X(I+1)-X(I)                                                 AKR01630
      B1=2./3.*(Y(I)*SIN(ALPHA1))**3                                     AKR01640
      B2=2./3.*(Y(I+1)*SIN(ALPHA2))**3                                   AKR01650
      SUM9=SUM9+(A1+A2)/2.*DELTAX                                        AKR01660
      SUM10=SUM10+(B1+B2)/2.*DELTAX                                      AKR01670
      SUM11=SUM11+(X(I)*A1+X(I+1)*A2)/2.*DELTAX                          AKR01680
C                                                                        AKR01690
C     STORE THE AMMOUNT OF HELIUM AND AIR IN EACH SETION FOR LATER USE   AKR01700
C     IN THE INERTIA CALCULATIONS.                                       AKR01710
C                                                                        AKR01720
      DAIR(I)=(A1+A2)/2.*DELTAX                                          AKR01730
      DHEL(I)=PI*(Y(I)**2+Y(I+1)**2)/2.*DELTAX-DAIR(I)                   AKR01740
      HAIR(I)=(B1+B2)/2.*DELTAX/DAIR(I)                                  AKR01750
      HHEL(I)=-DAIR(I)*HAIR(I)/DHEL(I)                                   AKR01760
  110 CONTINUE                                                           AKR01770
      VAIR(J)=SUM9                                                       AKR01780
      VHEL(J)=VCL(J)-VAIR(J)                                             AKR01790
      IF(VAIR(J).EQ.0.)GO TO 111                                         AKR01800
      ZBARA(J)=SUM10/VAIR(J)                                             AKR01810
      ZBARH(J)=VAIR(J)*ZBARA(J)/(VAIR(J)-VCL(J))                         AKR01820
      XBARA(J)=SUM11/VAIR(J)                                             AKR01830
      XBARH(J)=(VCL(J)*VCENTR(J)-XBARA(J)*VAIR(J))/VHEL(J)               AKR01840
      GO TO 100                                                          AKR01850
  111 CONTINUE                                                           AKR01860
      XBARA(J)=0.                                                        AKR01870
      XBARH(J)=VCENTR(J)                                                 AKR01880
      ZBARA(J)=0.                                                        AKR01890
      ZBARH(J)=0.                                                        AKR01900
  100 CONTINUE                                                           AKR01910
      WRITE(6,211) D                                                     AKR01920
```

```
      WRITE(6,212) (VAIR(J),J=1,M)
      WRITE(6,213) (VHEL(J),J=1,M)
      WRITE(6,214) (XBARA(J),J=1,M)
      WRITE(6,215) (XBARH(J),J=1,M)
      WRITE(6,216) (ZBARA(J),J=1,M)
      WRITE(6,217) (ZBARH(J),J=1,M)
211   FORMAT(//,10X,'DSTANCE FROM CENTER LINE TO TOP OF AIR LAYER =',
     +F5.2,' FT ')
212   FORMAT(//,2X,'AIR VOLUME',4X,8(1X,E12.6))
213   FORMAT(//,2X,'HEL VOLUME',4X,8(1X,E12.6))
214   FORMAT(//,2X,'XBAR AIR',6X,8(1X,E12.6))
215   FORMAT(//,2X,'XBAR HEL',6X,8(1X,E12.6))
216   FORMAT(//,2X,'ZBAR AIR',6X,8(1X,E12.6))
217   FORMAT(//,2X,'ZBAR HEL',6X,8(1X,E12.5))
C
C   NOW FIND THE ENGINE WEIGHT IN EACH SEGMENT
C
      XENG(1)=322.6
      XENG(2)=322.6
      XENG(3)=475.2
      XENG(4)=475.2
      YENG(1)=62.6
      YENG(2)=-62.6
      YENG(3)=60.
      YENG(4)=-60.
      ZENG(1)=47.2
      ZENG(2)=47.2
      ZENG(3)=46.
      ZENG(4)=46.
      DO 170 J=1,4
      DO 170 K=1,M
      YE(J,K)=0.
      XE(J,K)=0.
      ZE(J,K)=0.
      WE(J,K)=0.
170   CONTINUE
      DO 180 J=1,M
      NE=0
      DO 180 K=1,4
      IF((XENG(K).LT.X(NDIV(J))).OR.(XENG(K).GT.X(NDIV(J+1)))) GO TO 180
      NE=NE+1
      XE(NE,J)=XENG(K)
      YE(NE,J)=YENG(K)
      ZE(NE,J)=ZENG(K)
      WE(NE,J)=WENGS/4.
180   CONTINUE
C
C   THE FRAME MASS IS ASSUMED TO BE CONCENTRATED IN THE SHELL AND SO
```

```
C     THE MOMENT ON INERTIA CAN BE CALCULATED USING THE SHELL DENSITY SDEN
C
      SDEN=WFRAME/32.2/SURFAC
      DO 120 J=1,N
      MFRAME(J)=SDEN*ASURF(J)
      XBARF(J)=CAPROJ(J)
120   CONTINUE
C
C     CALCULATE THE BUOYANT FORCES
C
      BSUM=0.
      CBX=0.
      DO 320 I=1,N
      BUOY(I)=RHOAIR*VOL(I)*32.2
      BSUM=BSUM+BUOY(I)
      CBX=CBX+BUOY(I)*VCENTR(I)
320   CONTINUE
      CBX=CBX/BSUM
C
C     SOLVES FOR THE POSITION OF THE KEEL SO THAT THE CG LIES UNDER THE
C     CENTER OF BUOYANCY
C
      XCEG=0.
      EMTOT=0.
      DO 312 I=1,N
      CMHEL=VHEL(I)*RHOHEL
      CMAIR=VAIR(I)*RHOAIR
      CMFRAM=MFRAME(I)
      EMXE=0.
      CMENGS=0.
      DO 325 J=1,4
      CMENGS=CMENGS+WE(J,I)/32.2
325   EMXE=EMXE+WE(J,I)*XE(J,I)/32.2
      CMTOT=CMHEL+CMAIR+CMFRAM+CMENGS
      XCEG=XCEG+CMHEL*XBARH(I)+CMAIR*XBARA(I)+CMFRAM*XBARF(I)+EMXE
      EMTOT=EMTOT+CMHEL+CMAIR+CMFRAM+CMENGS
312   CONTINUE
      XCEG=XCEG+WFINS/32.2*XFINS
      EMTOT=EMTOT+WFINS/32.2
      CKEEL=((EMTOT+WKEEL/32.2)*CBX-XCEG)/(WKEEL/32.2)
C
C     NEXT FIND THE PORTION OF THE KEEL IN EACH SEGMENT
C     LENGTH OF KEEL = TWICE THE DISTANCE FROM THE CONTROL CAR TO THE CB
C
      LK=466.07
      ZKEEL=66.
      SKEEL=CKEEL-LK/2.
      FKEEL=CKEEL+LK/2.
```

```
      IFLAG=0
      DO 160 K=1,N
      X1=X(NDIV(K))
      X2=X(NDIV(K+1))
      IF(IFLAG.EQ.1) GO TO 153
      IF((X1.LT.SKEEL).AND.(X2.LT.SKEEL))GO TO 153
      IF((X1.LT.SKEEL).AND.(X2.GT.SKEEL)) GO TO 151
      IF((X1.LT.FKEEL).AND.(X2.GT.FKEEL))GO TO 152
      LKEEL(K)=X2-X1
      XKEEL(K)=(X1+X2)/2.
      GO TO 160
151   LKEEL(K)=X2-SKEEL
      XKEEL(K)=(X2+SKEEL)/2.
      GO TO 160
152   LKEEL(K)=FKEEL-X1
      XKEEL(K)=(FKEEL+X1)/2.
      IFLAG=1
      GO TO 160
153   LKEEL(K)=0.
      XKEEL(K)=0.
160   CONTINUE
      DO 150 J=1,N
      WK(J)=LKEEL(J)/LK*WKEEL
150   CONTINUE
C
C    CALCULATES THE CG
C
      CGX=0.
      CGH=0.
      DO 190 I=1,M
      CMHEL=VHEL(I)*RHOHEL
      CMAIR=VAIR(I)*RHOAIR
      CFRAM=MFRAME(I)
      CMKEEL=WK(I)/32.2
      EMZE=0.
      EMXE=0.
      CMENGS=0.
      DO 326 J=1,4
      CMENGS=CMENGS+WE(J,I)/32.2
      EMXE=EMXE+WE(J,I)*XE(J,I)/32.2
326   EMZE=EMZE+WE(J,I)*ZE(J,I)/32.2
      CMTOT=CMHEL+CMAIR+CMFRAM+CMKEEL+CMENGS
      CWTOT(I)=CMTOT*32.2
      WTOT=WTOT+(CMHEL+CMAIR)*32.2
      XCG(I)=(CMHEL*XBARH(I)+CMAIR*XBARA(I)+CMFRAM*XBARF(I)+CMKEEL*XKEEL
     $(I)+EMXE)/CMTOT
      YCG(I)=0.
      ZCG(I)=(CMHEL*ZBARH(I)+CMAIR*ZBARA(I)+CMKEEL*ZKEEL+EMZE)/CMTOT
```

```
      CGX=CGX+XCG(I)*CMTCT
      CGH=CGH+ZCG(I)*CMTCT
  190 CONTINUE
      CGX=(CGX+WFINS/32.2*XFINS)/WTOT*32.2
      CGH=CGH*32.2/WTOT
C
C     FRAME CONTRIBUTION TO MOMENTS OF INERTIA
C
      DO 130 J=1,M
      IXXF(J)=0.
      IYYF(J)=0.
      IZZF(J)=0.
      IXZ(J)=0.
      K1=NDIV(J)
      K2=NDIV(J+1)-1
      DO 140 I=K1,K2
      THETA=ATAN(ABS((Y(I+1)-Y(I))/(X(I+1)-X(I))))
      A=(Y(I+1)-Y(I))/(X(I+1)-X(I))
      B=Y(I)-A*X(I)
      IXXF(J)=IXXF(J)+(FUNC2(A,B,X(I+1),ZCG(J))-FUNC2(A,B,X(I),ZCG(J)))
     +*2.*SDEN*PI/COS(THETA)
      IYYF(J)=IYYF(J)+(FUNC1(A,B,X(I+1),XCG(J),ZCG(J))-
     +FUNC1(A,B,X(I),XCG(J),ZCG(J)))*PI*SDEN/COS(THETA)
      IZZF(J)=IZZF(J)+(FUNC1(A,B,X(I+1),XCG(J),0.)-FUNC1(A,B,X(I),XCG(J)
     +,0.))*PI*SDEN/COS(THETA)
      IXZ(J)=IXZ(J)+(FUNC3(A,B,X(I+1),XCG(J))-FUNC3(A,B,X(I),XCG(J)))*2.
     +*PI*SDEN*ZCG(J)/COS(THETA)
  140 CONTINUE
  130 CONTINUE
C
C     ENGINE CONTRIBUTIONS
C
      DO 300 I=1,M
      SIXXE(I)=0.
      SIYYE(I)=0.
      SIZZE(I)=0.
      DO 300 J=1,4
      SIXXE(I)=SIXXE(I)+WE(J,I)/32.2*(YE(J,I)**2+(ZE(J,I)-ZCG(I))**2)
      SIYYE(I)=SIYYE(I)+WE(J,I)/32.2*((XE(J,I)-XCG(I))**2+
     +(ZE(J,I)-ZCG(I))**2)
      SIZZE(I)=SIZZE(I)+WE(J,I)/32.2*((XE(J,I)-XCG(I))**2+YE(J,I)**2)
      IXZ(I)=IXZ(I)+WE(J,I)/32.2*(XCG(I)-XE(J,I))*(ZE(J,I)-ZCG(I))
  300 CONTINUE
C
C     AIR AND HELIUM CONTRIBUTION
C
      DO 410 J=1,M
      K1=NDIV(J)
```

```
      K2=NDIV(J+1)-1
      IXX(J)=IXXF(J)+SIXXE(J)+WK(J)/32.2*(ZKEEL-ZCG(J))**2
      IYY(J)=IYYF(J)+SIYYE(J)+WK(J)/32.2*(LKEEL(J)**2/12.+(XKEEL(J)-
     +XCG(J))**2+(ZKEEL-ZCG(J))**2)
      IZZ(J)=IZZF(J)+SIZZE(J)+WK(J)/32.2*(LKEEL(J)**2/12.+(XKEEL(J)-
     +XCG(J))**2)
      IXZ(J)=IXZ(J)+WK(J)/32.2*(XCG(J)-XKEEL(J))*(ZKEEL-ZCG(J))
      DO 410 I=K1,K2
      IXX(J)=IXX(J)+DAIR(I)*RHOAIR*(ZCG(J)-HAIR(I))**2+DHEL(I)*RHOHEL*
     +(ZCG(J)-HHEL(I))**2
      IYY(J)=IYY(J)+DAIR(I)*RHOAIR*((X(I)-XCG(J))**2+(HAIR(I)-ZCG(J))**2
     +)+DHEL(I)*RHOHEL*((X(I)-XCG(J))**2+(HHEL(I)-ZCG(J))**2)
      IZZ(J)=IZZ(J)+DAIR(I)*RHOAIR*(X(I)-XCG(J))**2+DHEL(I)*RHOHEL*
     +(X(I)-XCG(J))**2
      IXZ(J)=IXZ(J)+DAIR(I)*RHOAIR*(XCG(J)-X(I))*(HAIR(I)-ZCG(J))+
     +DHEL(I)*RHOHEL*(XCG(J)-X(I))*(HHEL(I)-ZCG(J))
410   CONTINUE
C
C     FIN CONTRIBUTION
C
      CIXX=12751.
      CIYY=34796.5
      CIZZ=47547.2
      CIXZ=1336.2
      FM=WFINS/32.2/4.
      ZF=35.268
      XF=667.48
      IXXFIN=2.*(CIXX+FM*(ZF**2+CGH**2))+(CIXX+FM*(ZF+CGH)**2)+
     +(CIXX+FM*(ZF-CGH)**2)
      IYYFIN=2.*(CIYY+FM*(CGH**2+(XF-CGX)**2))+(CIZZ+FM*((ZF+CGH
     +)**2+(XF-CGX)**2))+(CIZZ+FM*((ZF-CGH)**2+(XF-CGX)**2))
      IZZFIN=2.*(CIZZ+FM*((XF-CGX)**2+ZF**2))+2.*(CIYY+FM*(XF-CGX)**2)
      IXZFIN=4.*FM*CGH*(XF-CGX)+2.*CIXZ
C
C     SUM UP COMPONENT PARTS TO GET IXX,IYY,IZZ, AT THE AIRSHIP CG
C
      IXXTOT=0.0
      IYYTOT=0.0
      IZZTOT=0.0
      IXZTOT=0.0
      DO 411 I=1,N
      IXXTOT=IXXTOT+IXX(I)+CWTOT(I)/32.2*(CGH-ZCG(I))**2
      IYYTOT=IYYTOT+IYY(I)+CWTOT(I)/32.2*((CGX-XCG(I))**2+(CGH-ZCG(I))**
     +2)
      IZZTOT=IZZTOT+IZZ(I)+CWTOT(I)/32.2*(CGX-XCG(I))**2
      IXZTOT=IXZTOT+IXZ(I)+CWTOT(I)/32.2*(CGX-XCG(I))*(ZCG(I)-CGH)
411   CONTINUE
      IXXTOT=IXXTOT+IXXFIN
```

```
      IYYTOT=IYYTCT+IYYFIN                                              AKR04330
      IZZTOT=IZZTCT+IZZFIN                                              AKR04340
      IXZTCT=IXZTCT+IXZFIN                                              AKR04350
      WRITE(6,218) (XCG(I),I=1,M)                                       AKR04360
      WRITE(6,219) (ZCG(I),I=1,M)                                       AKR04370
      WRITE(6,220) (CWTOT(I),I=1,M)                                     AKR04380
      WRITE(6,221) (BUCY(I),I=1,M)                                      AKRC4390
      WRITE(6,222) (IXX(I),I=1,M)                                       AKR04400
      WRITE(6,223) (IYY(I),I=1,M)                                       AKR04410
      WRITE(6,224) (IZZ(I),I=1,M)                                       AKR04420
      WRITE(6,228) (IXZ(I),I=1,M)                                       AKR04430
      WRITE(6,226) CKEEL                                                AKR04440
      WRITE(6,225) CGX,CGH,CBX,WTOT,BSUM                                AKR04450
      WRITE(6,227) IXXTOT,IYYTOT,IZZTOT,IXZTCT                          AKR04460
  218 FORMAT(//,2X,'XCG(I)',8X,8(1X,E12.6))                             AKR04470
  219 FORMAT(//,2X,'ZCG(I)',8X,8(1X,E12.6))                             AKR04480
  220 FORMAT(//,2X,'SEGMENT WEIGHT',8(1X,E12.6))                        AKR04490
  221 FORMAT(//,2X,'BUOYANCY',6X,8(1X,E12.6))                           AKR04500
  222 FORMAT(//,2X,'IXX(I)',8X,8(1X,E12.6))                             AKR04510
  223 FORMAT(//,2X,'IYY(I)',8X,8(1X,E12.6))                             AKR04520
  224 FORMAT(//,2X,'IZZ(I)',8X,8(1X,E12.6))                             AKR04530
  225 FORMAT(//,10X,'MASS CENTER X ',E14.6,//,10X,'MASS CENTER Z ',     AKR04540
     $E14.6,//,10X,'BUOYANT CENTER',E14.6,//,10X,'TOTAL WEIGHT  ',      AKR04550
     $E14.6,//,10X,'BUOYANT FORCE ',E14.6)                              AKR04560
  226 FORMAT(//,10X,'KEEL CENTER = ',E14.6)                             AKR04570
  227 FORMAT(//,10X,'IXX TCTAL =    ',E14.6,//,10X,'IYY TOTAL =    ',   AKR04580
     $E14.6,//,10X,'IZZ TOTAL =    ',E14.6,//,10X,'IXZ TOTAL =    ',    AKR04590
     $E14.6,/////)                                                      AKRC4600
  228 FORMAT(//,2X,'IXZ(I)',8X,8(1X,E12.5))                             AKR04610
      TIYY=0.                                                           AKR04620
      DO 999 J=1,M                                                      AKR04630
      TIYY=TIYY+MFRAME(J)*((CGX-XCG(J))**2+(CGH-ZCG(J))**2)+IYYF(J)     AKR04640
  999 CONTINUE                                                          AKR04650
      STOP                                                              AKR04660
      END                                                               AKR04670
      FUNCTION FUNC1(A,B,X,EL,H)                                        AKR04680
      FUNC1=X**4/4.*(A**3+2*A)+X**3/3.*(3.*B*A*A+2.*B-4.*EL*A)+         AKR04690
     $X**2/2.*(3.*B*B*A+2.*EL**2*A-4.*EL*B+2.*H*H*A)+X*(B**3+2.*EL*EL*B+AKR04700
     $2.*H*H*B)                                                         AKR04710
      RETURN                                                            AKR04720
      END                                                               AKR04730
      FUNCTION FUNC2(A,B,X,H)                                           AKR04740
      FUNC2=A**3/4.*X**4+B*A*A*X**3+(3./2.*B*B*A+H*H*A)*X*X+            AKR04750
     $(B**3+2.*H*H*B)*X                                                 AKR04760
      RETURN                                                            AKR04770
      END                                                               AKR04780
      FUNCTION FUNC3(A,B,X,EL)                                          AKR04790
      FUNC3=A**3/3.*X**3+(B-EL*A)*X**2-B*EL*X                           AKR04800
```

```
      RETURN                                                            AKR04810
      END                                                               AKR04820
      FUNCTICN F(C)                                                     AKR04830
      REAL*8 F,D                                                        AKR04840
      DIMENSION X(100),Y(100)                                           AKR04850
      COMMCN/AIR/X,Y,VCLAIR,N                                           AKR04860
      SUM8=C.                                                           AKR04870
      L=N-1                                                             AKRC4880
      DO 60 I=1,L                                                       AKR04890
      CELTAX=X(I+1)-X(I)                                                AKR04900
      IF(Y(I).LT.C)GO TO 60                                             AKR04910
      IF(Y(I+1).LT.D)GC TO 60                                           AKR04920
      THETA1=DARCCS(D/Y(I))                                             AKR04930
      THETA2=CARCCS(C/Y(I+1))                                           AKR04940
      AREA1=Y(I)*(THETA1*Y(I)-D*SIN(THETA1))                            AKR04950
      AREA2=Y(I+1)*(THETA2*Y(I+1)-D*SIN(THETA2))                        AKRC4960
      SUM8=SLM8+(AREA1+AREA2)/2.*DELTAX                                 AKR04970
   60 CONTINUE                                                          AKR04980
      F=DBLE(SUM8-VCLAIR)                                               AKRC4990
      RETURN                                                            AKR05000
      END                                                               AKR05010
```

TABLE I

PARAMETERS FOR TURBULENCE

Altitude (ft)	Mission Segment*	Turbulence Component**	P_1 (unitless)	b_1 (ft/sec)	P_2 (unitless)	b_2 (ft/sec)	$\tilde{L}$ (ft)
0 - 1,000	Low Level Contour (rough terrain)	V	1.00	2.7	10^{-5}	10.65	500
0 - 1,000	Low Level Contour (rough terrain)	L, L	1.00	3.1	10^{-5}	14.06	500
0 - 1,000	C, C, D	V, L, L	1.00	2.51	0.005	5.04	500
1,000 - 2,500	C, C, D	V, L, L	0.42	3.02	0.0033	5.94	1750
2,500 - 5,000	C, C, D	V, L, L	0.30	3.42	0.0020	8.17	2500
5,000 - 10,000	C, C, D	V, L, L	0.15	3.59	0.00095	9.22	2500
10,000 - 20,000	C, C, D	V, L, L	0.062	3.27	0.00028	10.52	2500
20,000 - 30,000	C, C, D	V, L, L	0.025	3.15	0.00011	11.88	2500
30,000 - 40,000	C, C, D	V, L, L	0.011	2.93	0.000095	9.84	2500
40,000 - 50,000	C, C, D	V, L, L	0.0046	3.28	0.000115	8.81	2500
50,000 - 60,000	C, C, D	V, L, L	0.0020	3.82	0.000078	7.04	2500
60,000 - 70,000	C, C, D	V, L, L	0.00088	2.93	0.000057	4.33	2500
70,000 - 80,000	C, C, D	V, L, L	0.00038	2.80	0.000044	1.80	2500
above 80,000	C, C, D	V, L, L	0.00025	2.50	0	0	2500

*Climb, cruise, and descent (C, C, D)

**Vertical , lateral, and longitudinal (V, L, L)

TABLE II

LOAD RESPONSE TRANSFER FUNCTIONS

$$\frac{(dY_g)_h}{\Gamma} = \rho U_o^2 K \frac{dA}{d\xi} \exp(-i\Omega\xi \cos\alpha_o) d\xi$$

$$\frac{(Y_g)_s}{\Gamma} = -\rho \frac{U_o^2}{2} S_s [(C_{Y\beta})_s H(k_s)\eta_s] \exp(-i\Omega l_s \cos\alpha_o)$$

$$\frac{(Y_g)_{T_k}}{\Gamma} = -\rho \frac{U_o^2}{2} S_{T_k} (C_{Y\beta})_{T_k} \exp(-i\Omega l_{T_k} \cos\alpha_o)$$

$$\frac{(N_g)_{T_k}}{\Gamma} = \frac{(Y_g)_{T_k}}{\Gamma} (l_{cm} - l_{T_k})$$

$$\frac{(L_g)_{T_k}}{\Gamma} = \frac{(Y_g)_{T_k}}{\Gamma} (h_{cm} - h_{T_k})$$

$$\frac{(dY_w)_h}{\Gamma} = \Big\{ \rho U_o^2 K \frac{dA}{d\xi} \left[\frac{\hat{V}}{\Gamma} - \frac{2}{\bar{c}} (l_{cm} - \xi) \frac{\hat{R}}{\Gamma} \right]$$

$$+ \rho U_o^2 A \Big\{ i\Omega \left[\frac{\hat{V}}{\Gamma} - \frac{2}{\bar{c}} \frac{\hat{R}}{\Gamma} (l_{cm} - \xi) \right] k_2 + \frac{2}{\bar{c}} \frac{\hat{R}}{\Gamma} k_1 \Big\} \Big\} d\xi$$

$$\frac{(Y_w)_s}{\Gamma} = -\rho \frac{U_o^2}{2} S_s \Big\{ (C_{Y\beta})_s \left[\frac{\hat{V}}{\Gamma} - \frac{\hat{R}}{\Gamma} (l_{cm} - l_s) \right] + \left(C_{Y_r} \right)_s^{ac} \frac{\hat{R}}{\Gamma}$$

$$+ \frac{ik}{2} \left[\frac{\hat{V}}{\Gamma} - \frac{2}{\bar{c}} \frac{\hat{R}}{\Gamma} (l_{cm} - l_s) \right] \Big\}$$

$$\frac{(N_w)_s}{\Gamma} = \rho \frac{U_o^2}{2} S_s \bar{c}_s \left(C_{n_r} \right)_s^{ac} \frac{\hat{R}}{\Gamma}$$

$$\frac{(L_w)_s}{\Gamma} = \frac{(Y_w)_s}{\Gamma} (h_{cm})_s$$

$$\frac{(Y_w)_{T_k}}{\Gamma} = -\rho \frac{U_o^2}{2} S_{T_k} (C_{y_\beta})_{T_k} \left[\frac{\hat{V}}{\Gamma} - \frac{2}{\bar{c}} \frac{\hat{R}}{\Gamma} (l_{cm} - l_{T_k}) - \frac{2}{\bar{c}} \frac{\hat{P}}{\Gamma} (h_{cm} - h_{T_k}) \right]$$

$$\frac{(L_w)_{T_k}}{\Gamma} = \frac{(Y_w)_{T_k}}{\Gamma} (h_{cm} - h_{T_k})$$

$$\frac{(N_w)_{T_k}}{\Gamma} = \frac{(Y_w)_{T_k}}{\Gamma} (l_{cm} - l_{T_k})$$

$$\frac{(dY_m)_h}{\Gamma} = -\left[U_o^2 i\Omega \frac{\hat{V}}{\Gamma} + \frac{2}{\bar{c}} U_o^2 i\Omega \frac{\hat{R}}{\Gamma} (l_{cm} - \xi) + \frac{2U_o^2}{\bar{c}} \frac{\hat{R}}{\Gamma} \right] (dm)_h$$

$$\frac{(dL_m)_h}{\Gamma} = i\Omega \frac{2}{\bar{c}} U_o^2 (-dI_{xx} \frac{\hat{P}}{\Gamma} + dI_{xz} \frac{\hat{R}}{\Gamma})$$

$$\frac{(dN_m)_h}{\Gamma} = i\Omega \frac{2}{\bar{c}} U_o^2 (-dI_{zz} \frac{\hat{R}}{\Gamma} + dI_{xz} \frac{\hat{P}}{\Gamma})$$

$$\frac{(Y_m)_s}{\Gamma} = -\left[U_o^2 i\Omega \frac{\hat{V}}{\Gamma} + \frac{2}{\bar{c}} U_o^2 i\Omega \frac{\hat{R}}{\Gamma} (l_{cm} - l_s) + \frac{2U_o^2}{\bar{c}} \frac{\hat{R}}{\Gamma} \right] m_s$$

$$\frac{(L_m)_s}{\Gamma} = i\Omega \frac{2}{\bar{c}} U_o^2 \left[-(dI_{xx})_s \frac{\hat{P}}{\Gamma} + (dI_{xz})_s \frac{\hat{R}}{\Gamma} \right]$$

$$\frac{(N_m)_s}{\Gamma} = i\Omega \frac{2}{\bar{c}} U_o^2 \left[-(dI_{zz})_s \frac{\hat{R}}{\Gamma} + (dI_{xz})_s \frac{\hat{R}}{\Gamma} \right]$$

$$\frac{(dY_b)_h}{\Gamma} = (\rho g A d\xi - g dm) \cos\alpha_o \frac{\hat{\Phi}}{\Gamma}$$

$$\frac{(Y_c)_s}{\Gamma} = -\rho \frac{U_o^2}{2} S_s K_c \frac{\hat{\Psi}}{\Gamma}$$

$$\frac{(dL_{mg})_h}{\Gamma} = h_{cm}\, g\, d\, m \cos\alpha \frac{\hat{\Phi}}{\Gamma}$$

TABLE III

GEOMETRICAL AND INERTIAL PROPERTIES

OF THE USS AKRON (ZR-4)

total volume = 7,382,400 ft^3

$\bar{c}$ = 785.0 ft

s = 37,914 ft^2

l_{cm} = 364.24 ft

h_{cm} = -37.66 ft

l_b = 363.01 ft

mass = 17,039 slugs

buoyancy = 548,642 lb

I_{xx} = 38,685,100 slug-ft^2

I_{zz} = 471,799,000 slug-ft^2

I_{xz} = 102,129,000 slug-ft^2

TABLE IV

STABILITY DERIVATIVES OF THE USS AKRON (ZR-4)

neutral buoyancy, U_o = 123 ft/sec, ALT = 1000 ft

$C_{y_\beta} = -0.7224$	$C_{y_{\dot\beta}} = -0.9863$
$C_{y_r} = -0.3418$	$C_{y_{\dot r}} = 0.0586$
$C_{y_p} = -0.0648$	$C_{y_{\dot p}} = -0.0913$
$C_{n_\beta} = -0.1710$	$C_{n_{\dot\beta}} = 0.0293$
$C_{n_r} = -0.2352$	$C_{n_{\dot r}} = -0.0991$
$C_{n_p} = -0.0150$	$C_{n_{\dot p}} = 0.0028$
$C_{l_\beta} = -0.0322$	$C_{l_{\dot\beta}} = -0.0456$
$C_{l_r} = -0.0153$	$C_{l_{\dot r}} = 0.0028$
$C_{l_p} = -0.0066$	$C_{l_{\dot p}} = -0.0042$

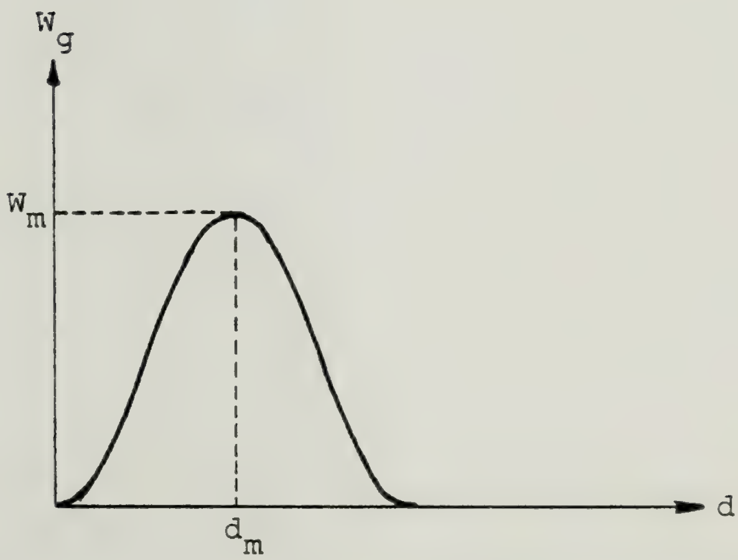

Figure 1. The (1-Cosine) Gust Shape

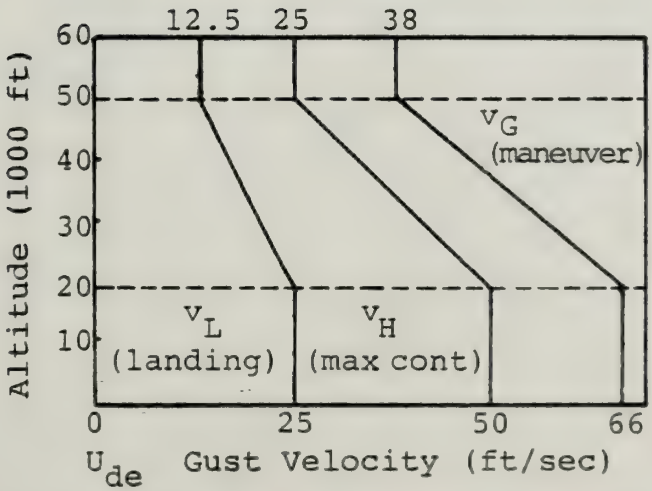

Figure 2. Derived Gust Velocity for Gust Loads Formula

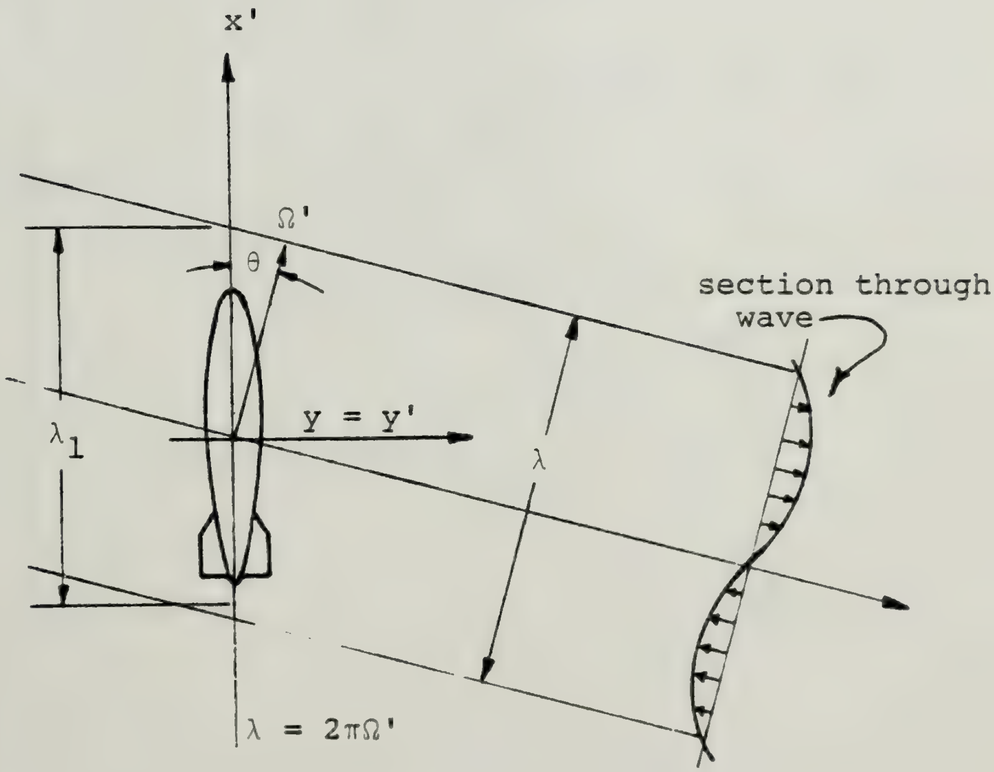

Figure 3. Elementary Spectral Components in Two Dimensions

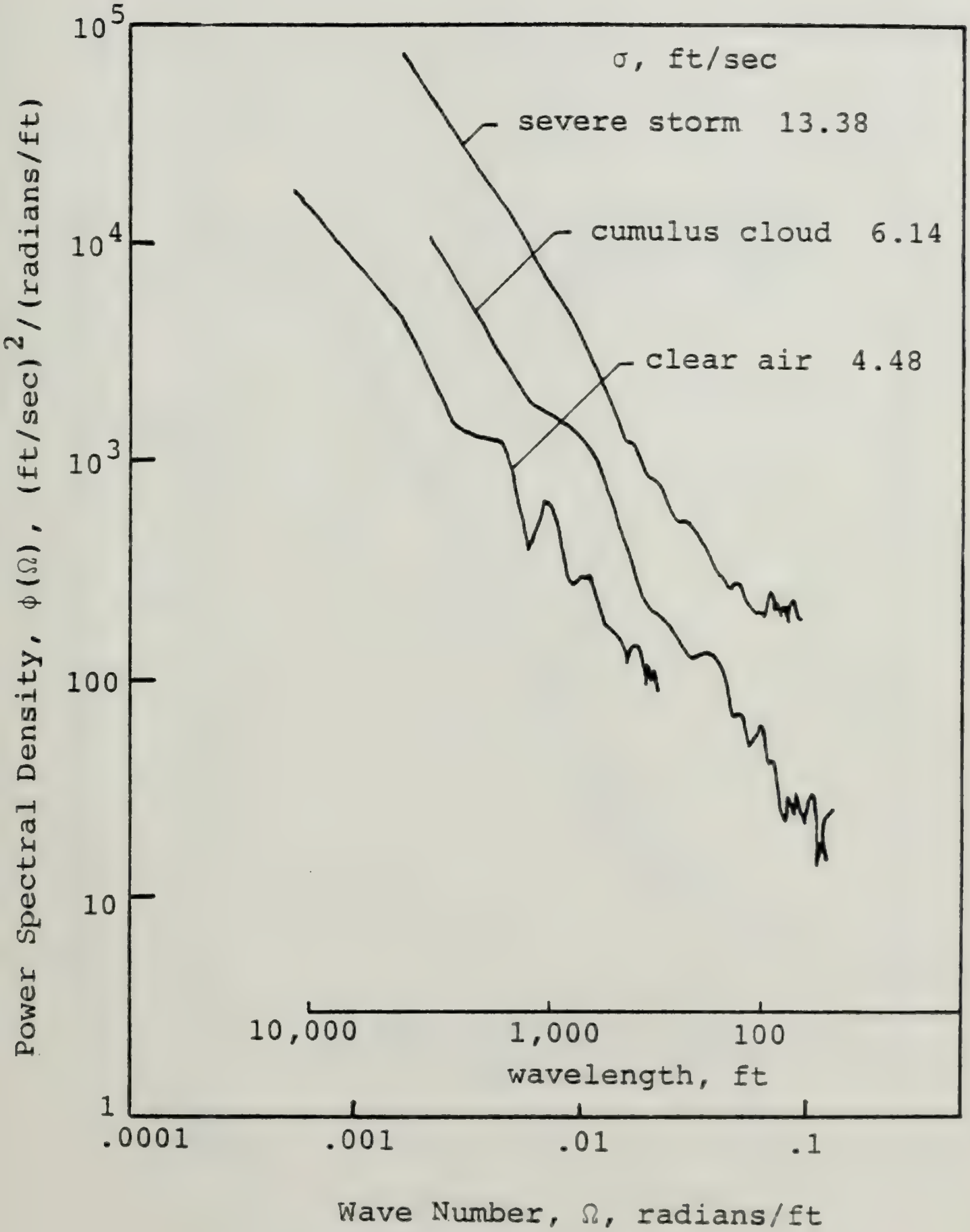

Figure 4. Typical Power Spectra of Vertical Gust Velocity

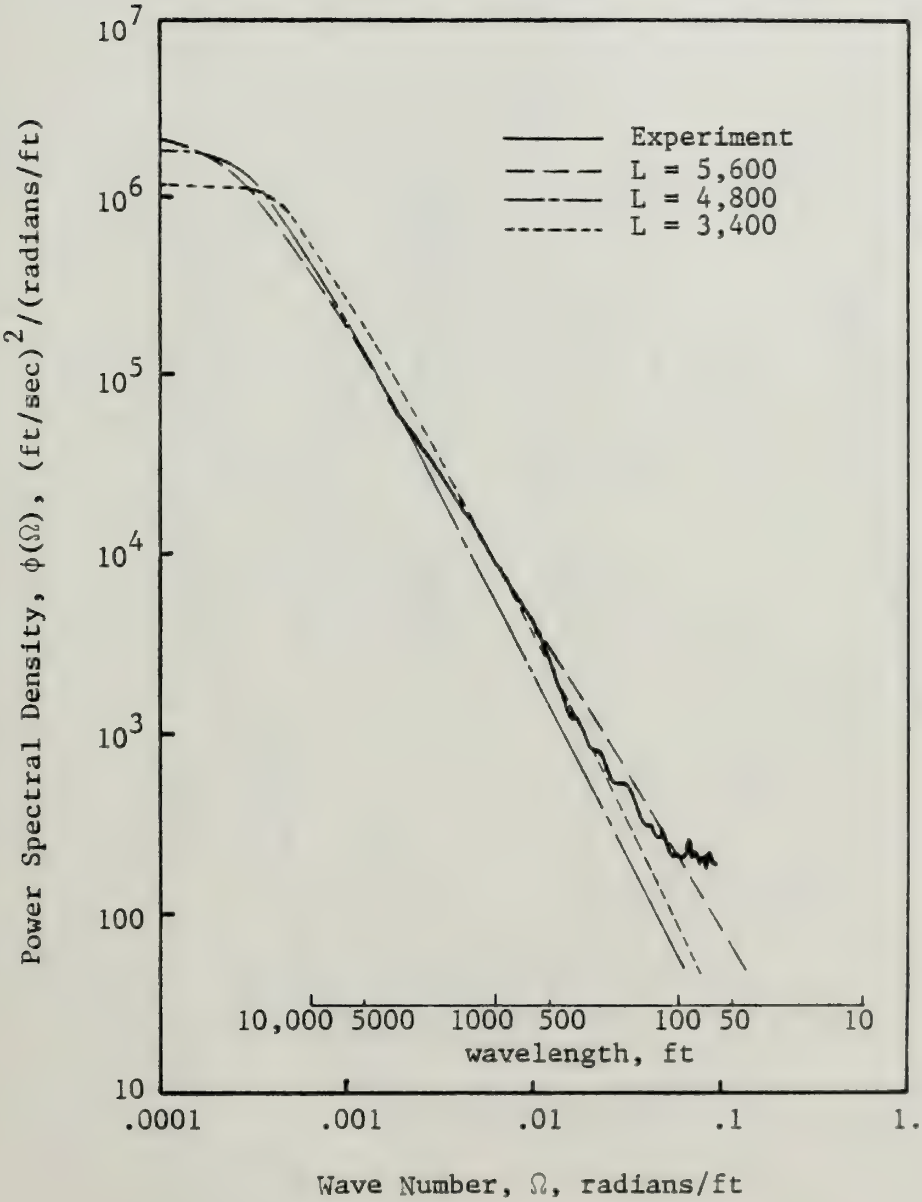

Figure 5. Measured and Fitted von Kàrmàn Spectra of Vertical Gust Velocity from Severe Storm

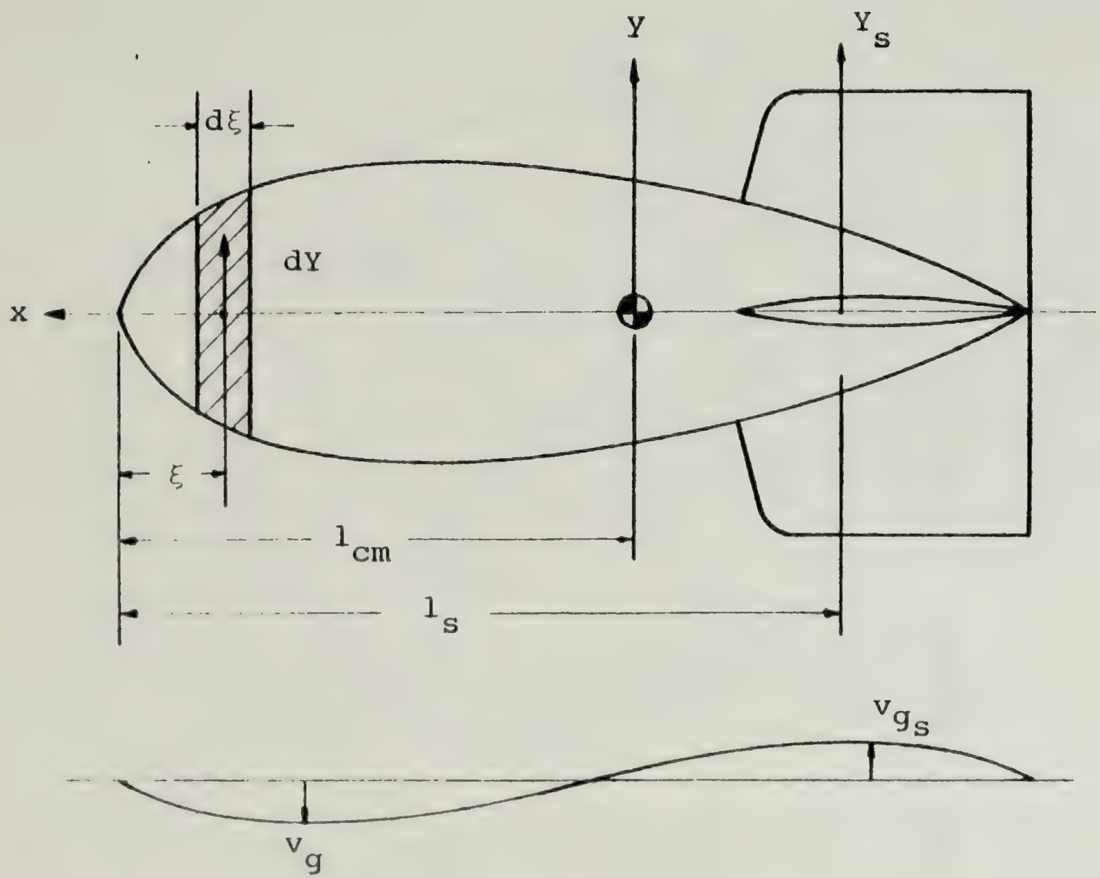

Figure 6. Schematic of Airship Loads from Turbulence

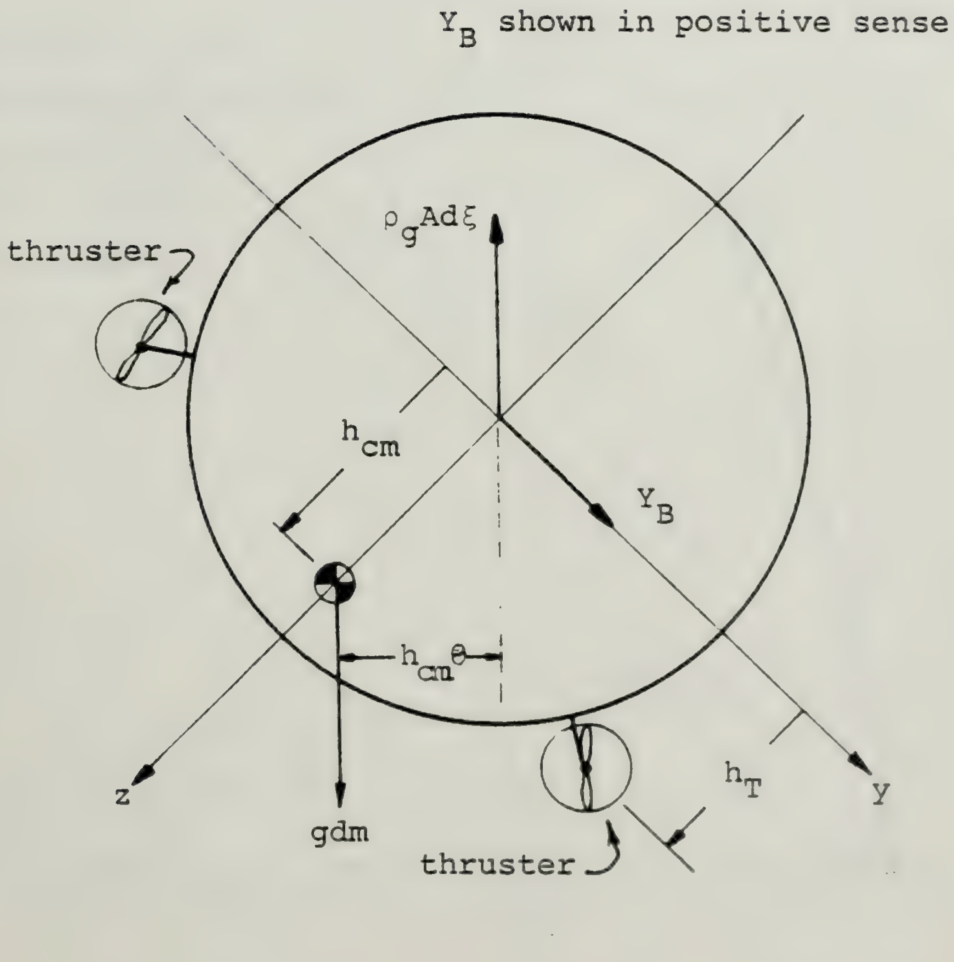

Figure 7. Schematic of Buoyancy Forces and Moments

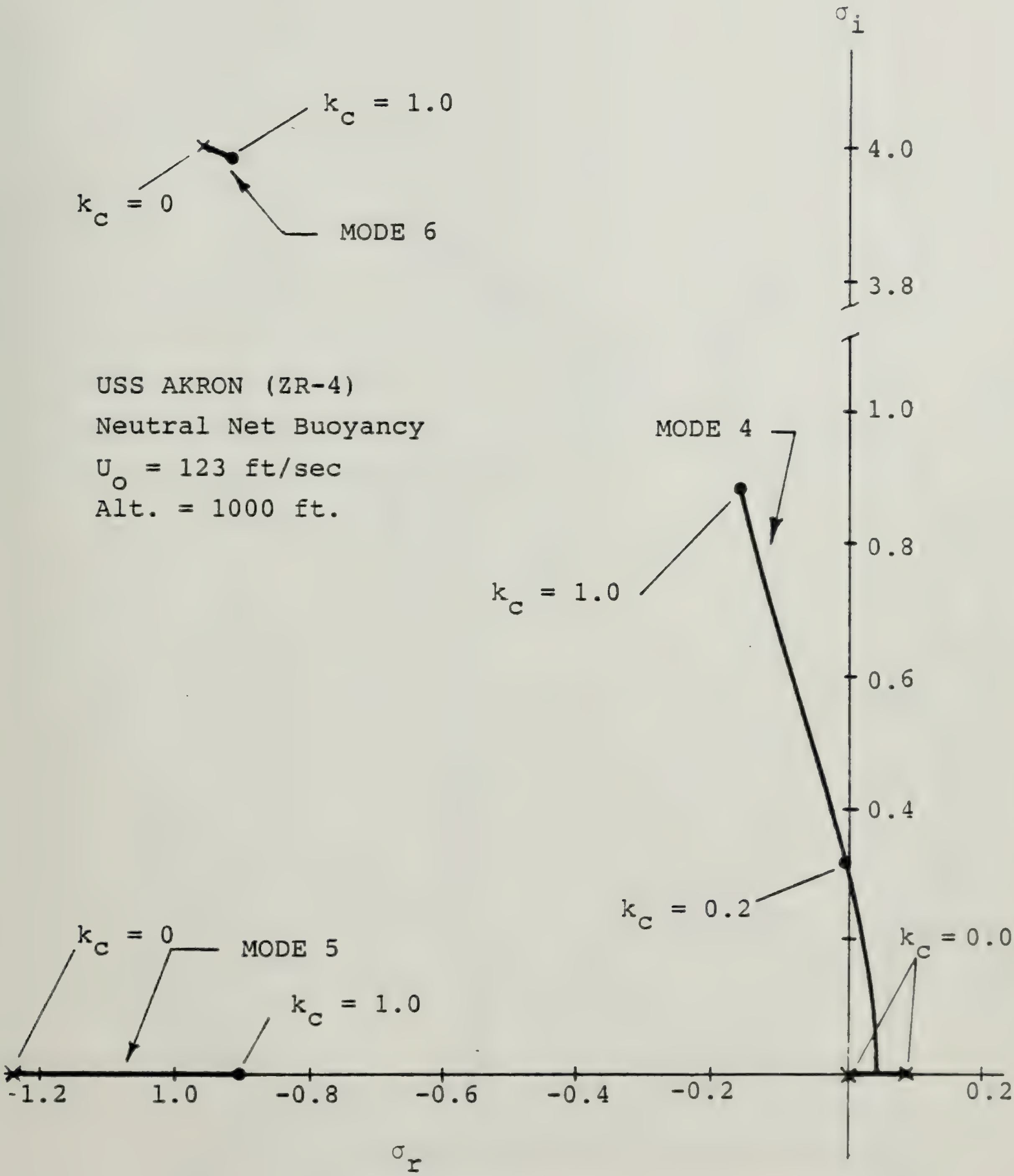

Figure 8. Lateral Root-Locus of the USS AKRON (ZR-4)

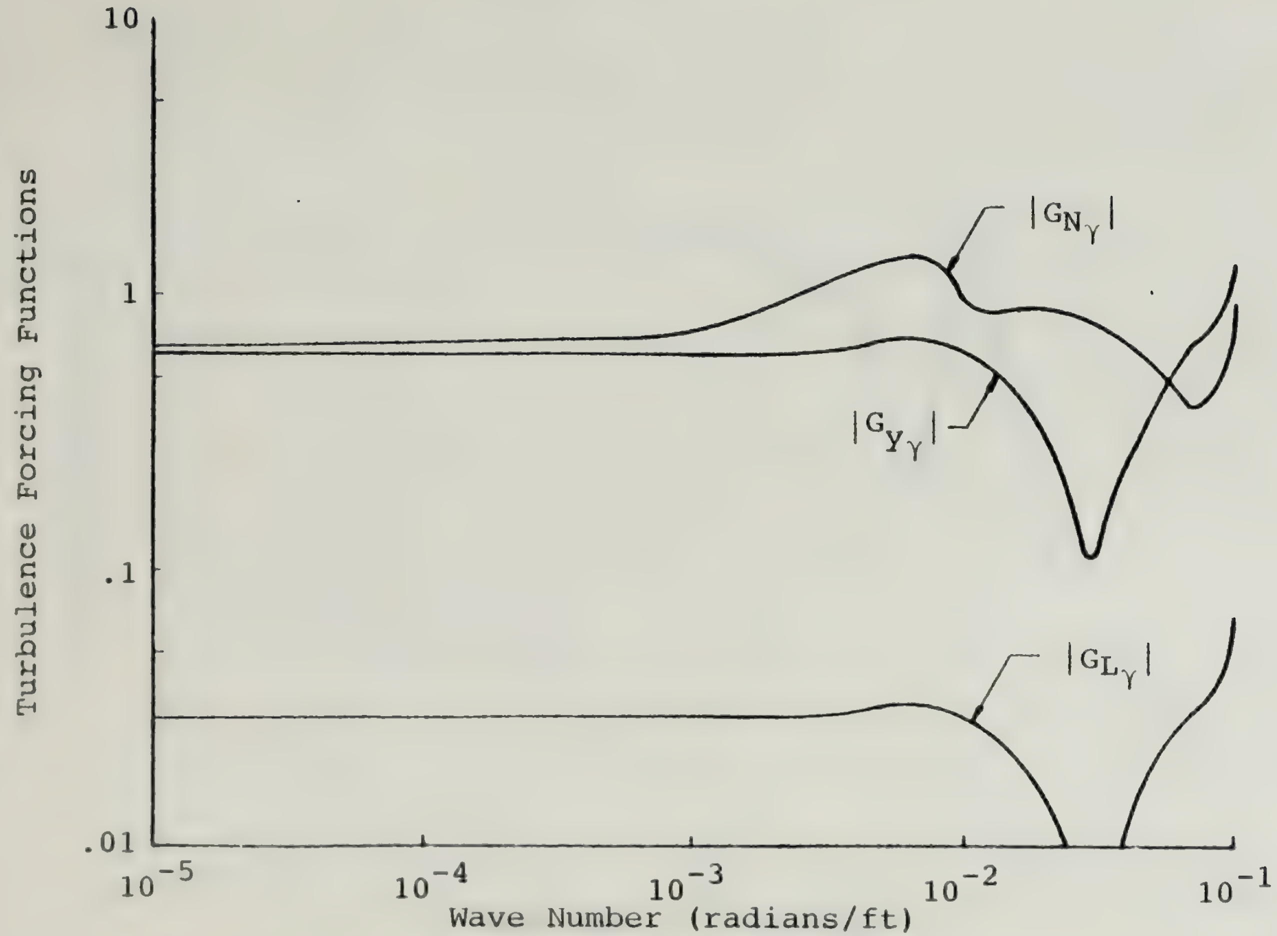

Figure 9. Turbulence Forcing Functions

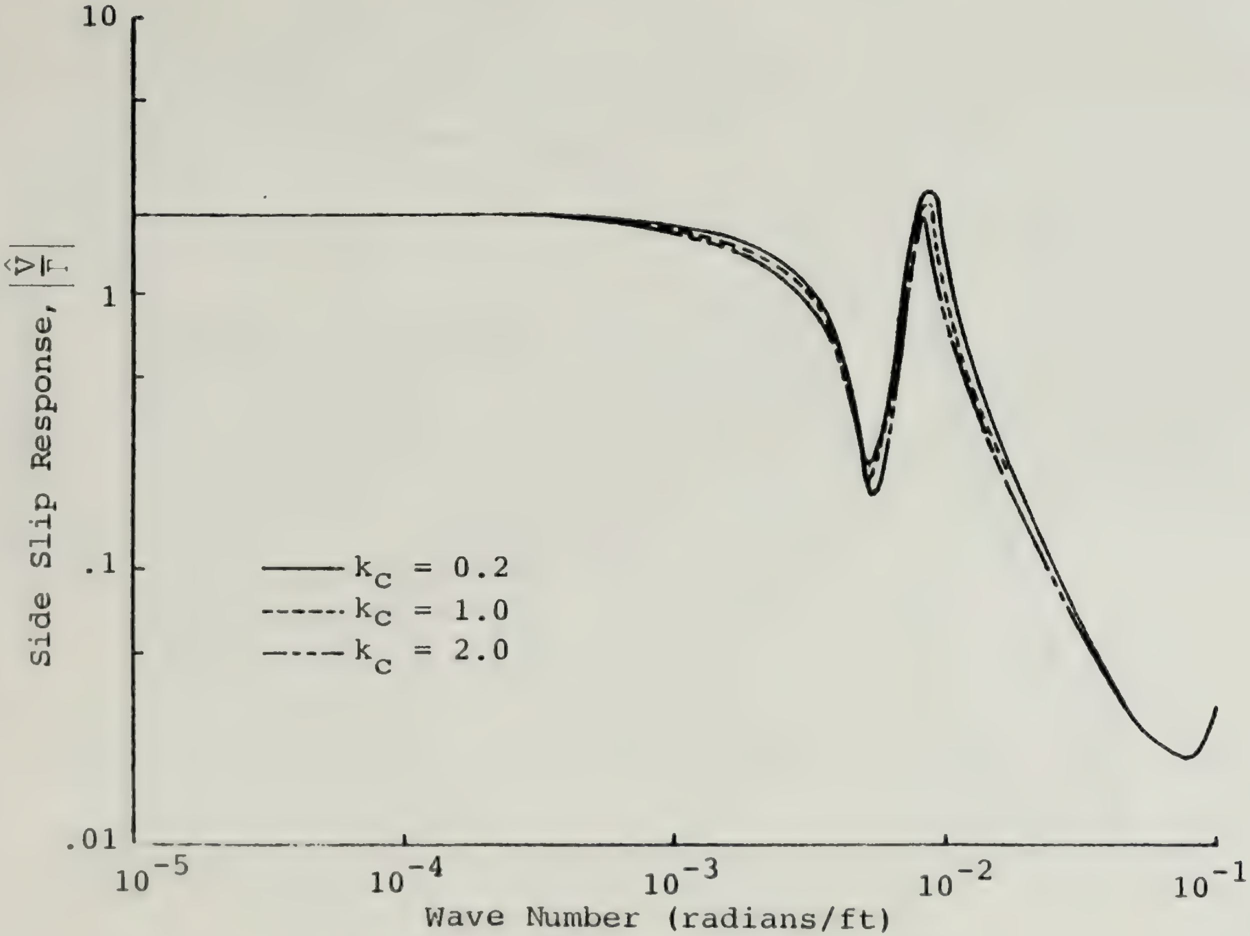

Figure 10. Side Slip Response

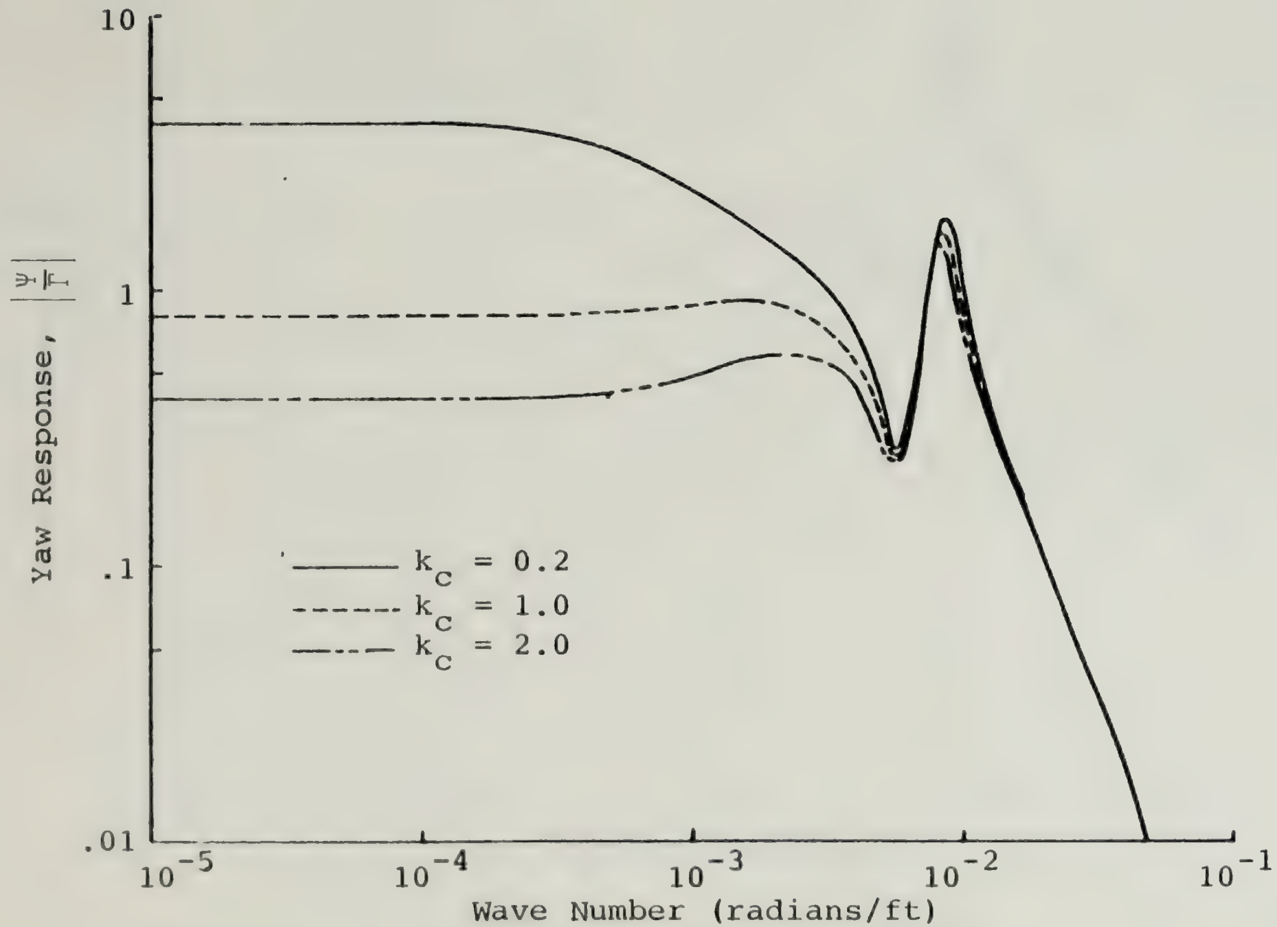

Figure 11. Yaw Response

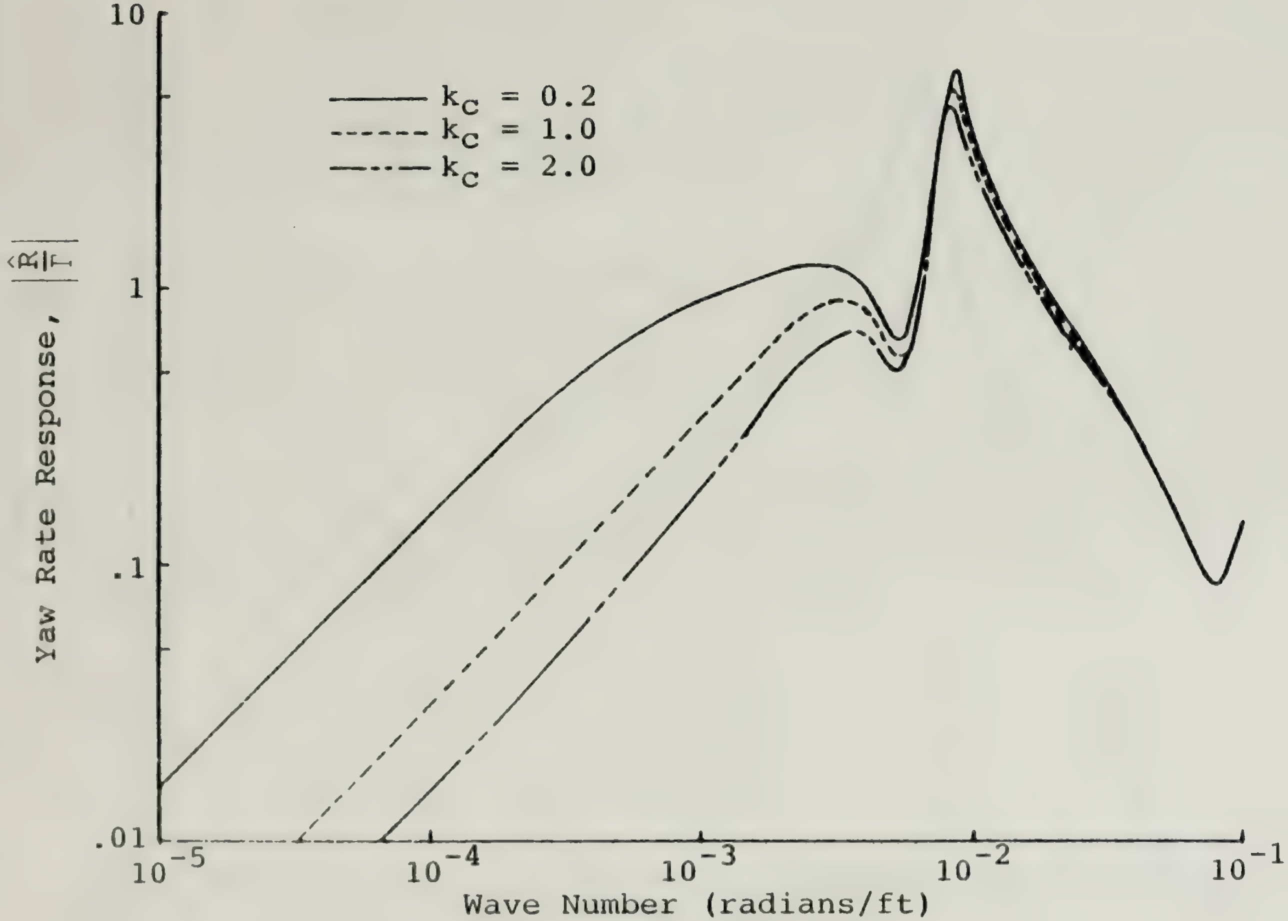

Figure 12. Yaw Rate Response

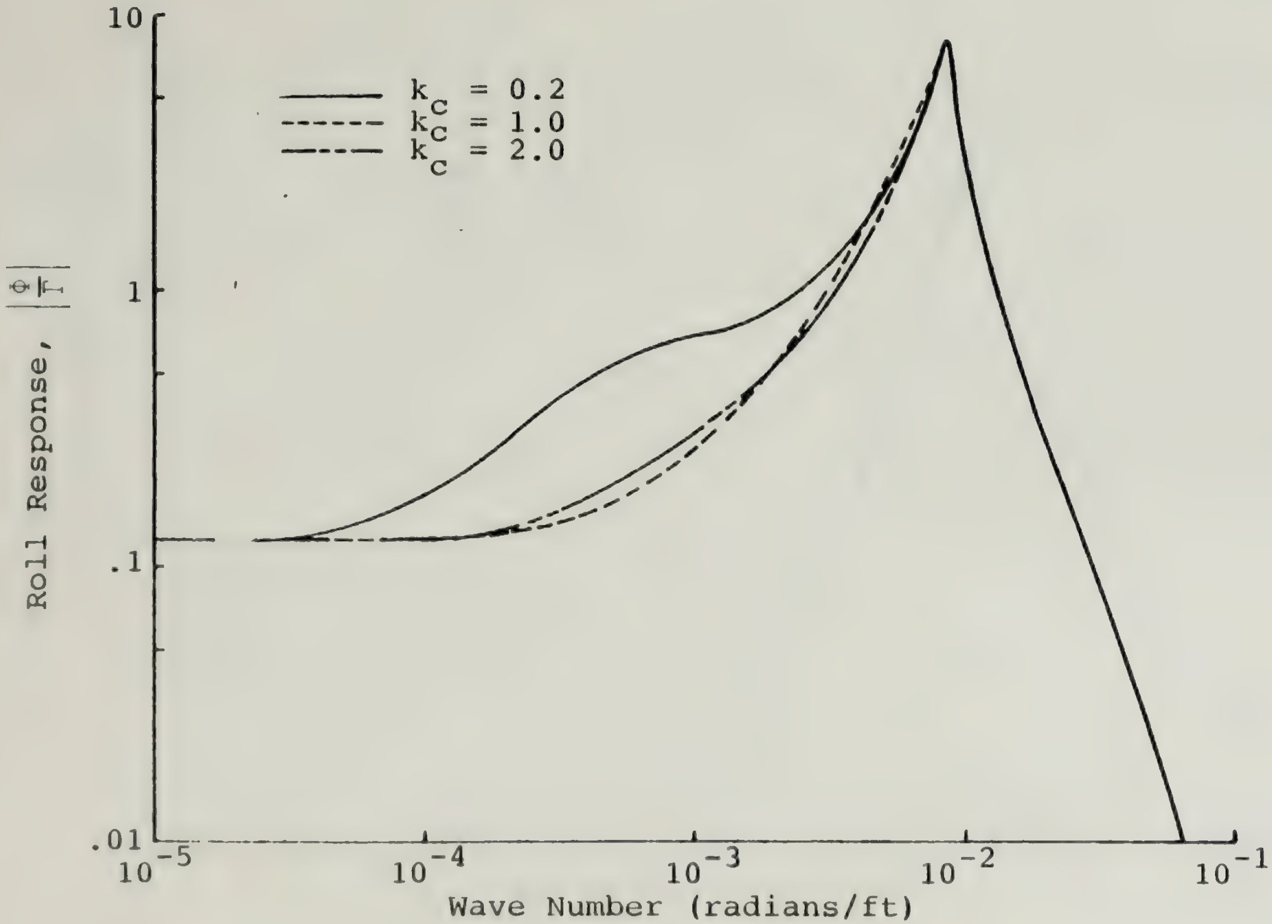

Figure 13. Roll Response

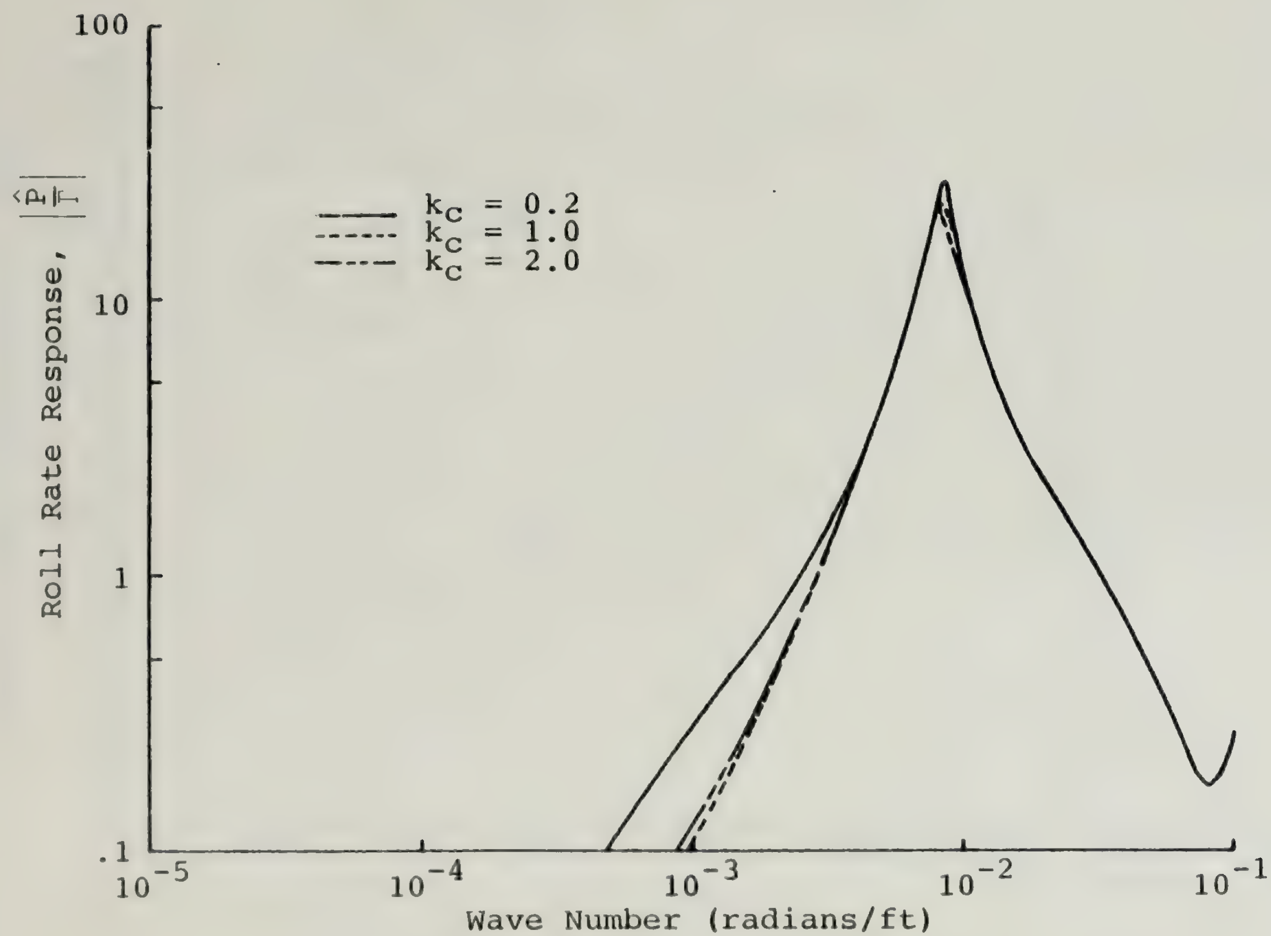

Figure 14. Roll Rate Response

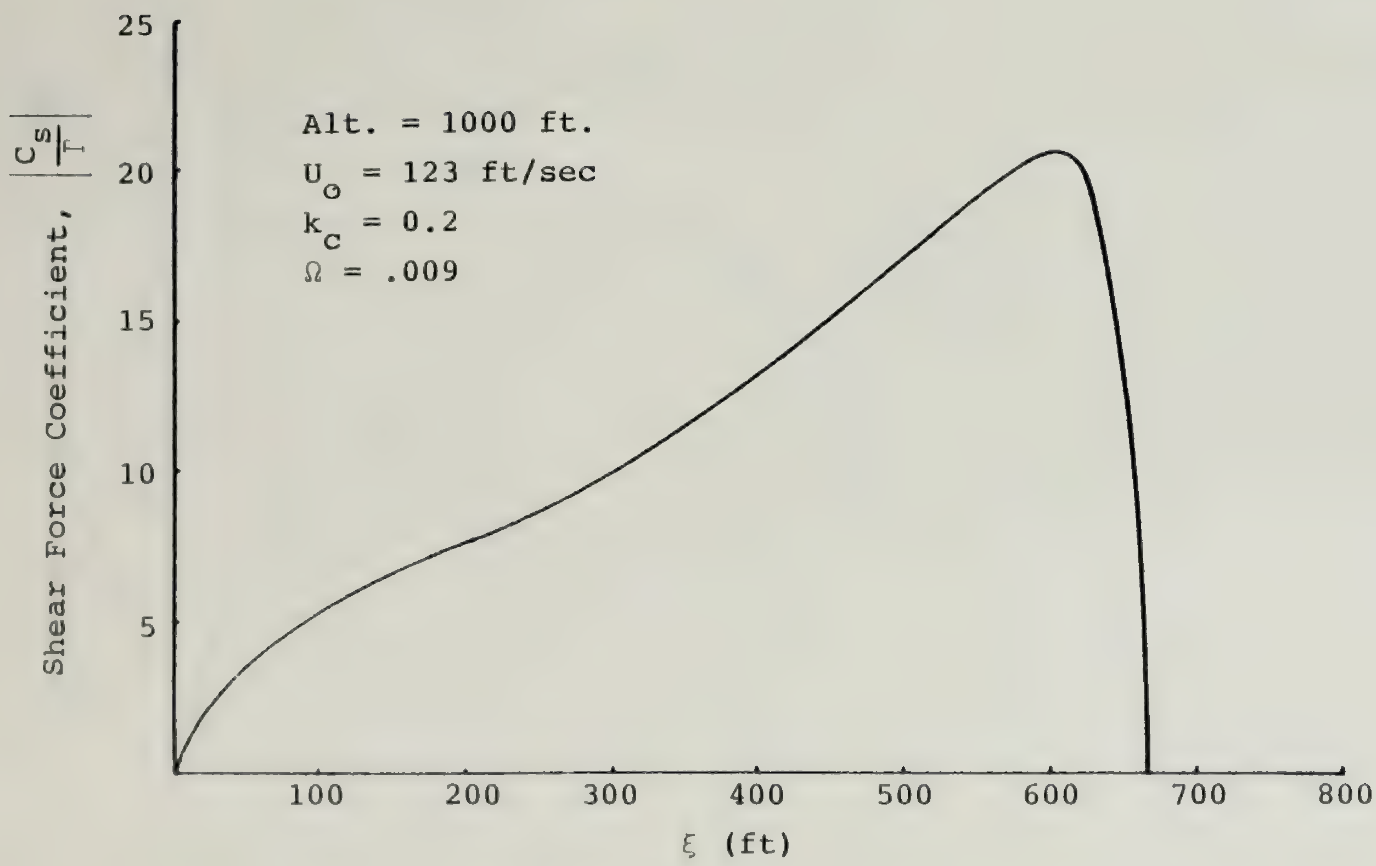

Figure 15. Shear Force Coefficient

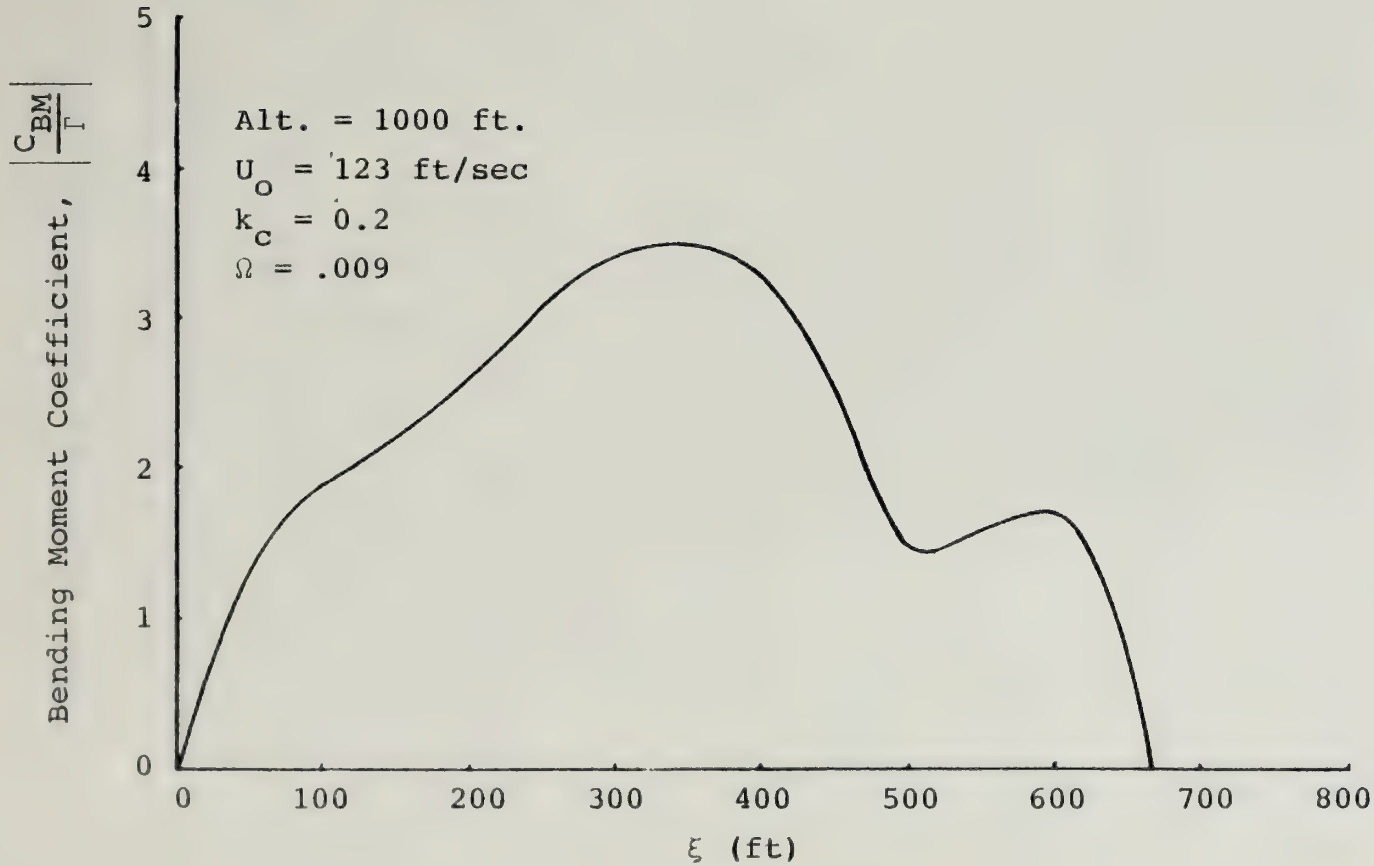

Figure 16. Bending Moment Coefficient

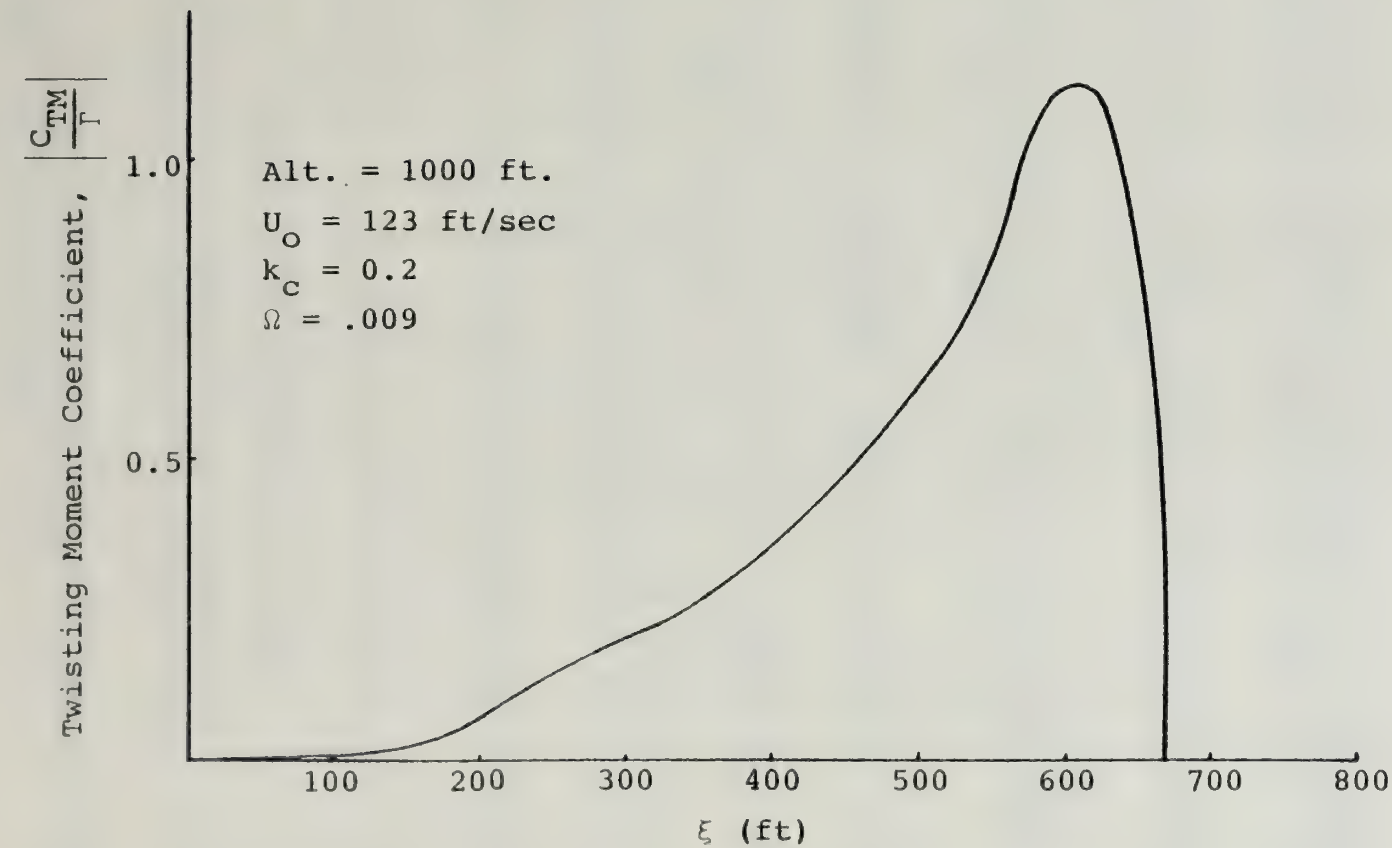

Figure 17. Twisting Moment Coefficient

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